B.H. LEVELTON & ASSOCIATES LIMITED

ESTABLISHMENT OF OPERATING PARAMETERS FOR EFFECTIVE MECHANICAL DEWATERING OF WOOD RESIDUES

Prepared for

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SUMMARY

A. Commercial Dewatering Equipment

Presses for dewatering of wood and bark residues come in various sizes and designs. Proven dewatering equipment that is used to various degrees in Canada for wood residues is of the following designs and makes:

Roll Press	- Fulton Iron Works Co.
Chain Press	- FMP-Rauma
Roll/Perforated Drum Press	- Saalasti Oy
Ram Press	- S.W. Hooper and Co. Ltd.

Presses which have been tested with wood residues, but are not in industrial use are available from Sunds Defibrator and Stake Technology. Enzo-Gutzeit markets a roll/perforated drum press used industrially in Finland for wood residues.

Equipment available for dewatering wood residues reduces moisture content to between 45% and 55%, wb, with the norm being near 50%, wb. Under good conditions and when it is well maintained and operated most commercial equipment can reduce the moisture content to 45%, wb. As a general rule, the higher the equipment throughput, the higher the product moisture content. Capacities of standard models range from near 1 t/h to somewhat more than 11 t/h. For a given product moisture content, capacities are subject to the properties of the material being pressed and its initial moisture content.

Problems with dewatering presses now in use as reported during a fairly limited sampling of the industry on the West Coast, include:

- failure and wear of major steel parts such as rolls, drums, chains etc., frames;
- plugging of drain holes;
- damage from foreign material;
- inability to reduce product moisture content to desired levels on a routine basis.

Some work is underway to develop new dewatering press designs. One new development is the Kamyr Ring Press developed by CRIQ. This is being marketed for pressing sludges and only limited tests with wood residues have been performed. These tests demonstrated the press could

reduce moisture content to 50%. Other laboratory work being done by Stake Technology using a modified form of their pressure feeder demonstrated that moisture contents of 45% or less could be achieved with wood residues. A report on the results of tests with a commercial-scale press has been prepared by the Company, but was not released for this study. No other designs showing promise were found during a fairly wide, though not exhaustive, survey of available technology and suppliers.

B. Experimentation and Theory for Dewatering

A simplified model of dewatering of solid wood was developed by Haygreen (1981). The results compared favourably with experimental data for softwood and hardwood species. Wingate-Hill (1985) compared the results from the model to results from dewatering of wood chips and found poor agreement, which he attributed to the assumption by Haygreen that the volumetric saturation of the lumen with water remained constant during compression of the wood as pressure was applied.

The approach to analysis of dewatering of solid wood was extended in this study to the analysis of dewatering of a mat of wood particles. This analysis leads to a generalized equation for the moisture content of a compressed mat of wood particles which is a function of volumetric compression and includes terms for the lumen saturation, the specific gravity of the wood, the moisture content of the wood substance and the densities of dry wood and the water adsorbed in the wood substance. To make practical use of the relationship, an equation is needed for lumen saturation as a function of compression.

Based on a preliminary examination of the experimental results from tests with the platen press it was hypothesized that the product of lumen saturation (S) and the ratio of the final volume to the initial volume (1-C) remained constant at some value called S*. With this simplifying assumption, the equation for moisture content reduces to:

$$MC = MC_i - kS^*\left(\frac{C}{1-C}\right)$$

where MC = moisture content after some compression C on a dry basis

MC_i = initial moisture content, dry basis

k = dimensionless constant involving dry wood density, bound water density and the moisture content of the wood substance as defined in Chapter IV

S* = a constant in the same units as moisture content

$$C = \frac{\text{Initial Volume - Final Volume}}{\text{Initial Volume}}$$

The most important result of this relationship is the apparent dependency of moisture content on the compression ratio C/(1-C). Experimental data for moisture content from tests with the platen press were plotted as a function of C/(1-C) to determine whether a linear relationship was obtained.

The assumption of the constancy of S(1-C) was based on observation and is at this time not based on a model for the displacement of air and water from the voids in the wood mat as it is compressed. Additional study of the simultaneous displacement of these materials from within the wood itself and the voids between the wood particles is needed to develop a true theoretical model of the dewatering process. The approach used is practical in that it hopefully provides a means of correlating results and, with such correlations, development of empirical relationships for predicting the moisture content of bulk wood materials under different pressing conditions and for materials having different physical properties.

C. Experimental Test Equipment

Laboratory scale tests were done with a platen press (184.2 mm diameter), a ram press (59 mm diameter) and a roller press (opposed rollers 219.1 mm diameter by 57.2 mm wide). All presses were actuated hydraulically.

Tests were done with clean wood chips and with hog fuel, both of Western Hemlock, as normally produced by a local sawmill in Vancouver. The feed materials were dewatered starting from two different initial moisture contents. One set of tests were done with feed at the normal as-produced moisture content, while another set was done after soaking the feed in water for 24 hours and allowing it to drain. The moisture content of the feed materials was near 50%, wb, as-received and 60% or more after soaking and draining. Other important feed properties were measured and documented.

D. Results of the Test Program

A comprehensive testing program was completed using the three laboratory presses to investigate key variables, specifically, pressure, initial moisture content, and type of feedstock. Additional tests were done with the platen press to study the effects of small changes in loading rate (limited by the available equipment) and of residence time at maximum pressure. Tests were done with the ram and roller press to determine what benefits would result by increasing the area available for removal of water from the compressed material.

Tests were done over the full pressure range possible with the available equipment. In all cases the highest pressure tested was

beyond that used in commercial equipment. For each condition studied, product moisture content was measured at different pressures over the range possible. These results are plotted in detail in Chapter VI.

The general shape of the dewatering curves for each press configuration is shown in Figure S-1 for wood chips and Figure S-2 for hog fuel. For both feedstocks, the platen press was the most effective for dewatering, requiring the least pressure to reach a given product moisture content. This is to be expected compared to the other designs since little of the applied pressure is used to overcome wall friction. The second most effective design for wood chips was the roll press. In the upper part of the pressure range tested with hog fuel, the ram press performed better than the roll press, yet it performed poorly at low pressures. This cross-over behavior is not present to any significant degree for the tests with wood chips.

At 25 MPa, the platen press reduced product moisture content to 36.5%, wb and 38.5%, wb for as-received and soaked wood chips, respectively. Product moisture contents for the platen press were 37.5%, wb and 43%, wb for as-received and soaked hog fuel. Wood chips were found to be more easily dewatered compared to hog fuel, the difference, as in this example being most pronounced for very wet feed.

E. Comparison of Test Results with Theory

The relationship presented earlier which gives moisture content on a dry basis as a function of the compression ratio C/(1-C) and physical properties of the material was used to correlate the test results for the platen press. These tests were selected for analysis because measurements of compression could be made, while this was not possible for the other two presses.

Average results from the tests done with residence times of one and two minutes are shown in Figures S-3 and S-4 for wood chips and hog fuel, respectively. In spite of the fact that S(1-C) is not constant over the pressure range studied as was hypothesized to develop the relationship, the plots for moisture content are surprisingly linear. Most of the data points are grouped together because this is the level of compression needed to achieve significant moisture removal. A more complete assessment of the correlation of moisture content with C/(1-C) could be made if additional data was obtained for the centre part of the range, which was not tested.

Correlations were determined for compression as a function of pressure in the platen press. With these relationships and the ones given in Figures S-3 and S-4, product moisture content can be predicted as a function of applied pressure. These correlations are valuable for investigating the effect of pressure and, with further study, could be used to consider the effects of material properties.

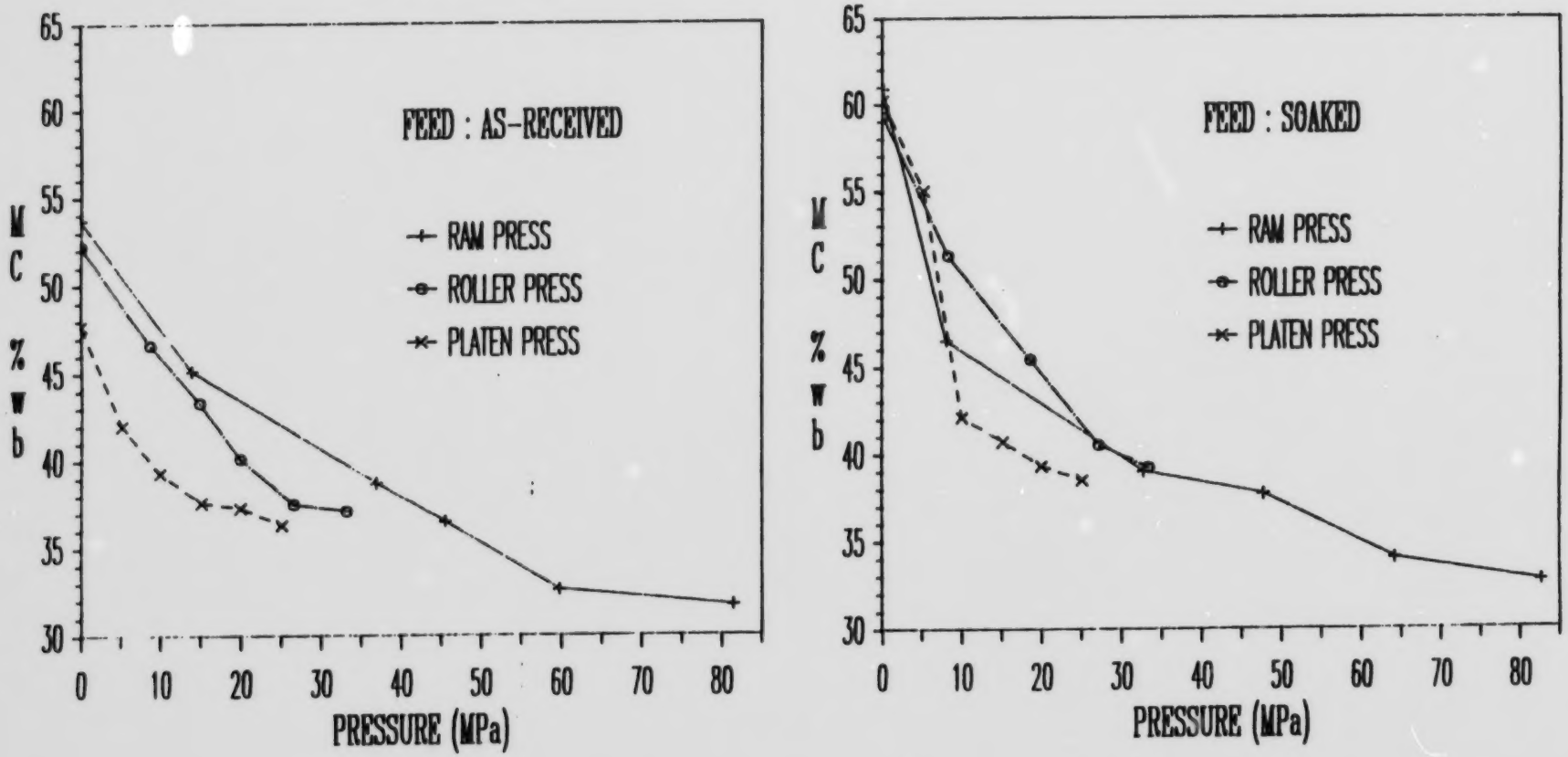


FIGURE S-1 COMPARISON OF PLATEN PRESS, RAM PRESS AND ROLLER PRESS TESTS FOR HEMLOCK WOOD CHIPS

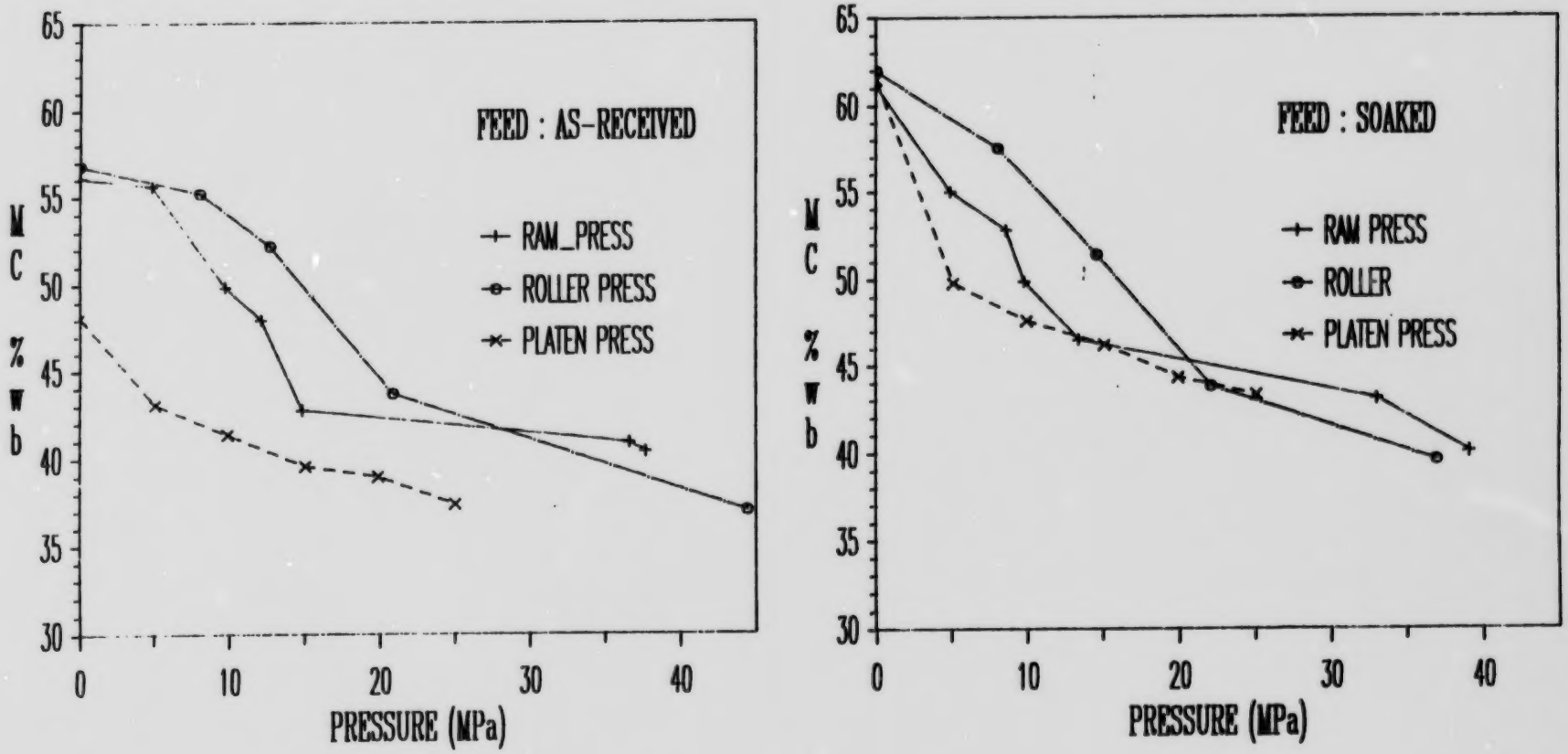


FIGURE S-2 COMPARISON OF PLATEN PRESS, RAM PRESS AND ROLLER PRESS TESTS FOR HEMLOCK HOG FUEL

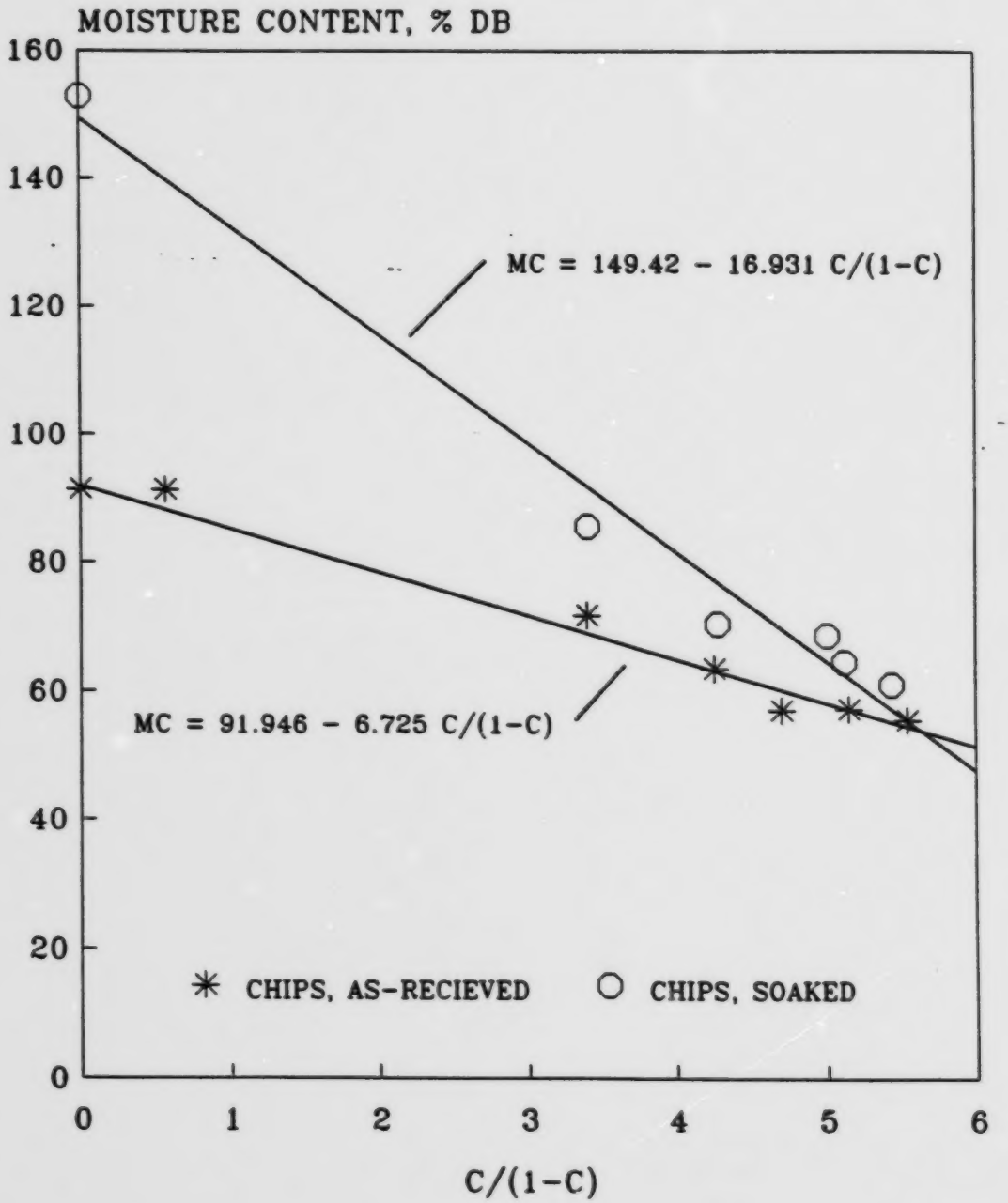


FIGURE S-3 RELATIONSHIP BETWEEN THE FINAL MOISTURE CONTENT OF HEMLOCK WOOD CHIPS C/(1-C)

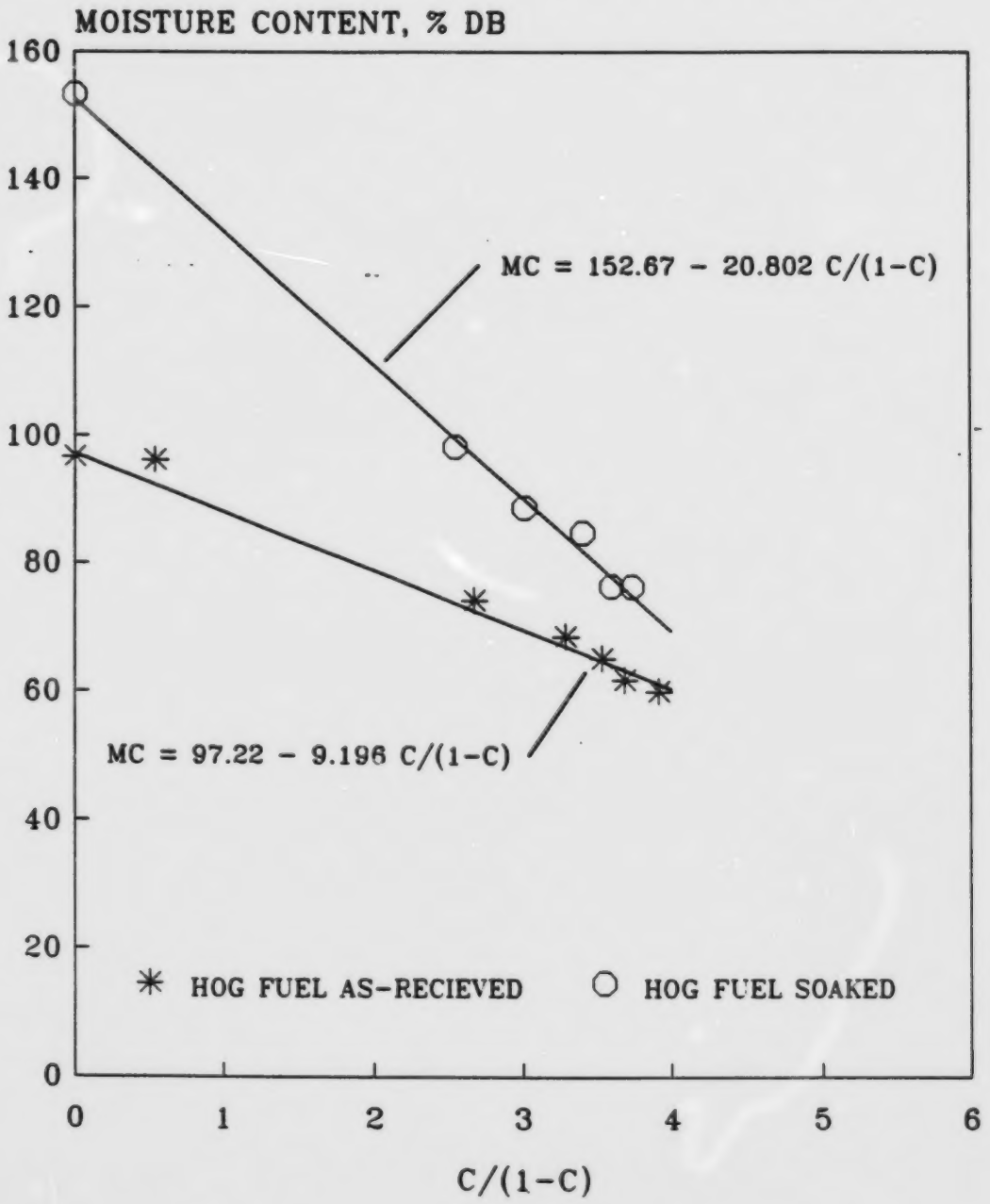


FIGURE S-4 RELATIONSHIP BETWEEN THE FINAL MOISTURE CONTENT OF HEMLOCK HOG FUEL AND C/(1-C)

The simplified theoretical approach provides a valuable tool for understanding the dewatering process for wood residues. Further theoretical work would help considerably in optimizing the performance of dewatering equipment and, possibly, in designing improved equipment. Work is recommended in the following areas:

- more complete testing with a platen press to improve on the correlations developed so far and determine if they can be applied over the full range of pressure;
- development of a relationship that incorporates the effect of initial moisture content;
- rationalization of the correlation coefficients and the materials' physical properties such as specific gravity, moisture content of the wood substance etc.;
- generalization of the theory to other geometries so it can be used to analyze roll presses or other designs. Correlation of data from other generic press designs is needed to determine whether the approach can be used for different press configurations.

F. Application of Experimental Results to Commercial Equipment

Based on test results and information on commercial presses, the following recommendations were made to improve the operation of current dewatering equipment:

- the press should provide a certain level of mat compression consistently;
- the control system should regulate mat compression;
- press operating conditions should be changed to suit the feed material since its dewatering characteristics will vary substantially;
- the duration of pressure application should be one minute or more;
- the press design should approximate a platen press in the dewatering area because of the effectiveness of this design;
- the mat entering the dewatering section should be of uniform thickness;
- drainage of the water from the mat should be effective and minimize readsorption.

An improved design of press is proposed. The design utilizes a low-pressure screw press and a high-pressure roll press for dewatering. The screw press doubles as a feeder for the roll press and provides a uniform mat thickness. The inner roll and outer perforated drum are of similar diameter to maximize the duration of pressure application and to proceed with dewatering in a single stage. However, additional stages may be needed. After additional theoretical work has been completed successfully, development and testing of the proposed design is recommended to establish its effectiveness and the throughput that can be achieved. To be attractive for industrial use, the throughput of a full-scale unit should be upwards of 10 dry t/h.

I. INTRODUCTION

Mechanical dewatering equipment is used widely in the forest products industry for reducing the moisture content of wood residue fuels. A prime candidate for mechanical dewatering is bark discharged from hydraulic debarkers, since its moisture content is typically in excess of 65%, wb. Many other residue streams in forest products mills have moisture contents in excess of 55%, wb. For all of these wet fuels, reduction of the moisture content is certainly beneficial and often essential before they can be burned efficiently and without combustion stability problems. Currently used mechanical dewatering equipment is capable on a routine basis of reducing the moisture content of wood residues to 50 - 55%, depending on the initial moisture content, the type of residue, the type of press used, the operational condition of the press and other variables. Under good conditions, product moisture contents can reach as low as 45%, but this is generally not the norm.

Mechanical dewatering presses have a lower capital cost than thermal drying systems for wet residues, but need routine maintenance and adjustment to keep them operating effectively. The cost of maintenance and the need for routine operating adjustments is a frequent complaint from industrial users. Thermal systems must be used to reduce moisture contents to 45%, wb, or below, since mechanical dewatering presses now available commercially are not capable of reaching these levels on a sustained basis. For drying wet feedstocks to low levels mechanical dewatering is pratical as a first stage to reduce the moisture content to, say, 50% wb, followed by thermal drying to the desired level.

When comparing mechanical and thermal methods of removing water from mat residues, the mechanical dewatering process has several advantages:

- no thermal energy is needed and, except possibly for dryers using flue gas as the heating medium, less energy is required per unit weight of water removed;
- less space is required;
- no emissions of air pollutants occur;
- capital cost is lower.

The main disadvantage of mechanical dewatering is that the product moisture content typically cannot be reduced below 50%, wb. Another consideration is that proper treatment of the effluent from dewatering presses is needed before it can be discharged to the environment because of the suspended solids and extractives that are present.

Very little study of the fundamentals of dewatering of wood residues such as hogged wood and bark has been reported in the published literature.

Undoubtedly the dewatering presses for wood residues currently marketed have been extensively tested, but this data is not publically available. As a result, there is a substantial lack of any information which could be used effectively to improve the performance of current dewatering presses, identify design changes which might yield a lower product moisture content, or relate the press performance to specific operating conditions and material properties.

This study was undertaken to address the lack of fundamental understanding of dewatering of wood residues and the need for more information on the type and performance of equipment currently used. Data on the operation of dewatering presses was obtained from suppliers and equipment users. This information formed a basis for designing a test program and for assessing the results that were measured in the laboratory. Tests were done at a laboratory scale to investigate three generic press configurations: platen press; ram press; and roller press. These designs are now used in one form or another in commercial dewatering presses. The laboratory results were correlated using a simple dewatering model, providing a valuable tool for predicting the effects of different operating conditions and material properties. The results of the test program, information obtained from users of dewatering presses and the fundamental understanding of dewatering obtained from a theoretical analysis were used to recommend means of improving existing presses and develop a new conceptual design.

II. OBJECTIVES

The objectives of this research are:

- To establish operating parameters (pressure, time, particle size, drainage patterns, etc.) for effective mechanical dewatering of wood particles using laboratory presses;

- To assemble data defining the performance of commercial equipment;

- To develop design parameters for equipment to reduce wood moisture content below levels presently reached with commercial equipment on a consistent basis;

- To recommend ways of improving existing equipment and develop designs for more effective equipment.

Fundamental to the test program is the use of press configurations which simulate to some degree presses in commercial use and which allow investigation of the effect of process variables on water removal. Tests were to be done at a laboratory scale to allow investigation of a large number of variables (i.e. press configurations, process variables and feed characteristics) economically and to yield results that could be related realistically to presses in commercial use. The test presses were not necessarily to be considered as potential new designs of commerical presses for wood and bark residues.

III. COMMERCIAL EQUIPMENT FOR DEWATERING

A. Wood/Bark Residues

Various designs of equipment are available commercially for dewatering of wood and bark residues. In general, mechanical dewatering is costly and is best suited to feed materials having a moisture content in excess of 55%, wet basis. The moisture content of the product is not strongly influenced by the moisture content of the feed, being normally in the range of 45% to 55%, wet basis. Achieving moisture content levels consistently in the lower end of this range is difficult and requires serious attention to proper equipment maintenance and operation.

Although some designs are more sensitive than others, dewatering equipment functions most effectively when fed at a uniform rate to produce a uniform mat thickness, and when no large single fuel pieces or chunks are present. If these conditions exist, the moisture content of the feed will be variable, worsening with the severity of the problem.

The key parameters for selection of dewatering equipment are:

- initial moisture content of the fuel;
- press capacity;
- type and size of feed;
- maximum piece size in feed;
- type and size of foreign material present;
- waste water treatment required.

The types of dewatering equipment may be classified by the means used for pressing. Commercial suppliers by type of press used are:

Roll Press	- Fulton Iron Works Co.
Chain Press	- FMP-Rauma
Roll/Perforated Drum Press	- Saalasti-Oy - Enso-Gutzeit Oy
Ram Press	- S.W. Hooper and Co. Ltd.

Screw Press - Sunds Defibrator Inc.

Hollow Piston/Screw Press - State Technology Ltd.

Table III-1 summarizes the specifications and performance of all proven equipment for dewatering wood and bark residues. Under optimal conditions, some of the presses will reduce the moisture content of the feed to 45%, but a value of 50% is more common in industry.

1. Fulton Iron Works Co.

Fulton Iron Works manufactures a roll press for dewatering of hogged wood and bark, bark and sludge mixtures, and other bulk materials. The press uses three grooved rolls (Figure III-1) arranged with two at the bottom and one at the top. Feed enters a hopper from the top and is drawn between the upper roll and the feed roll resulting in some water removal. The produced mat passes across a bridge plate from the nip of the feed roll to the nip of the discharge roll. The mat is further compressed in the nip of the discharge roll, removing more water, then is discharged from the press. Most water is removed when the mat is compressed in the nip of the discharge roll. The effective pressure in this area when processing hogged residues is about 17.2 MPa. Material is exposed to high pressure for 2 - 3 seconds. The pressure on the lower rolls from the single upper roll is maintained by adjustable hydraulic pressure, which can be set to a desired level.

One installation of the Fulton press at Alaska Pulp & Lumber in Sitka, Alaska was used up to 1981 for dewatering a mixture of bark and sludge. The bark feed was from a hydraulic debarker and, consequently, had a very high moisture content (70%, wet basis). The feed to the press consisted of 80% bark and 20% sludge and had a moisture content of about 90%. The Fulton press was found to work with bark feed, but to have difficulty with the bark/sludge feed. With bark only, the discharge had a moisture content of 57 - 58% when the rollers were in good condition, and 62 - 63% when the rollers were in poor condition.

The unit in Sitka was found to be easily damaged by foreign material such as bolts and nuts, that were present in the feed. The rolls were remachined every 2 - 3 months when operating the unit two-shifts per day on bark.

Damage of the rolls from foreign material must be guarded against by using suitable removal equipment. Such preventative measures are particularly important when foreign material is greater than 25 mm in size.

TABLE III-1 PERFORMANCE OF MECHANICAL DEWATERING EQUIPMENT

Equipment Description	Roll Press Fulton Iron Works Co.	Chain Press RMP-Raumm Ltd.
Best Application	Continuous process Very wet fuel Hogged clean bark	Continuous process Hogged or unhogged fuel
Maximum Acceptable Fuel Size	100 x 100 x 100 mm	100 x 100 x 100 mm occasional piece 100 mm dia x 1.2 m lg
Sensitivity to Rocks or Tramp Metal	Very high: 25 x 25 x 25 mm or smaller will pass without damage to press	Medium: 100 x 100 x 100 mm or smaller will pass without damage to press if mixed with hog fuel
Capacities Available	1.4 - 6.3 dry t/h	6.8 - 11.3 dry t/h
Models Available	400 x 400 mm 460 x 760 mm 580 x 900 mm	27 RMP 39 RMP 51 RMP
Minimum Final Moisture Content	45%	50%. Varies with size and initial fuel MC
Approximate Maintenance Costs	$ 0.77/dry t	$ 0.55/dry t
Proven Technology	Yes	Yes

- continued -

TABLE III-1 PERFORMANCE OF MECHANICAL DEWATERING EQUIPMENT

Equipment Description	Roll/Perforated Drum Press Bark Master, Saalasti-Oy	Roll/Perforated Drum Press Enso-Gutzeit Oy
Best Application	Continuous process. Very wet material. Hogged or unhogged bark.	Continuous process. Wet bark. Hogged and suitably sized for screw conveying.
Maximum Acceptable Fuel Size	Occasional piece: 200 x 200 x 600 mm lg	Occasional piece: Model 1400 x 500 Size 25 x 75 x 250 mm (1 x 3 x 10 in) Model 1700 x 750 Size 50 x 100 x 305 mm (2 x 4 x 12 in)
Sensitivity to Rocks or Tramp Metal	Low: Rocks smaller than 200 x 200 x 200 mm or tramp metal smaller than 500 mm dia x 600 mm lg or similar size can be processed without damage	Medium: Model 1400 x 500 — 1700 x 750 Rocks 0-75 mm dia — 0-100 mm dia Tramp Metal 0-35 mm dia — 0-50 mm dia
Capacities Available	8 - 11 dry t/h	2.2 - 3.8 dry t/h
Models Available	2500 mm Drum Length 1580 mm Drum I.D. One model only	1400 x 500 1700 x 750
Minimum Final Moisture Content	55%	45%
Approximate Maintenance Costs	$ 0.22/dry t	$ 0.28/dry t
Proven Technology	Yes	Experience in Finland only

- continued -

TABLE III-1 PERFORMANCE OF MECHANICAL DEWATERING EQUIPMENT

Equipment Description	Ram Press S.W. Hooper and Co. Ltd.	Screw Press Sunds Defibrator Inc.
Best Application	Minimum capital cost. Can tolerate intermittent fuel feed hogged or unhogged fuel.	Continuous process. Well hogged fuel.
Maximum Acceptable Fuel Size	Any size that can enter the hopper but large solid pieces will reduce dewatering efficiency	Occasional piece: 50 x 100 x 25 mm
Sensitivity to Rocks or Tramp Metal Tramp Metal	Low: Hydraulic overload protection prevents machine damage	Medium: Model M71 M70 Rocks 0-57 mm dia 0-70 mm dia and Tramp Metal
Capacities Available	5.5 dry t/h	1.5 - 3.8 dry t/h
Models Available	#10 only	M-71 250 mm dia Screw M-70 432 mm dia Screw
Minimum Fuel Moisture Content	45%	52%
Approximate Maintenance Costs	$ 0.33/dry t	$ 0.33/dry t
Proven Technology	Yes	Yes

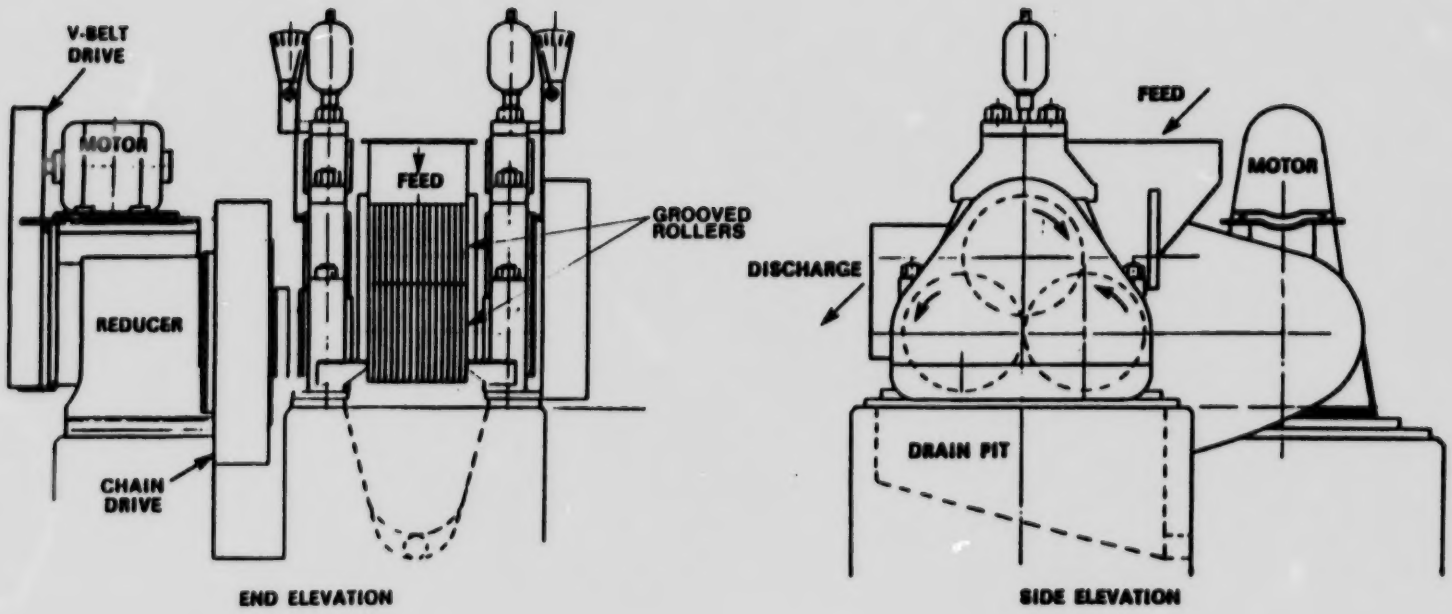


FIGURE III-1 FULTON IRON WORKS ROLL PRESS

Performance data quoted by the manufacterer is summarized in Table III-2.

TABLE III-2 PERFORMANCE AND CAPACITY DATA FOR THE FULTON ROLL PRESS

	MODEL		
	400 x 400	450 x 760	580 x 900
Feed rate (dry t/h)	1.4	3.2	6.3
Product moisture content (%)	45[a]	45	45
Power Requirement			
kW	18	37	56
kWh/dry t	12.9	11.6	8.9

[a] Independent of feed moisture content

2. FMP-Rauma

FMP-Rauma now markets the FMP bark press previously available from Horton CBI, Ltd. This is a chain press (Figure III-2) which utilizes the press developed by the chain on an unpowered roll to dewater wood and bark residues. Wet feed enters the press at the top and is pressed between the chain and the roll before discharge. Pressure on the material is produced by the action of three hydraulically actuated cells and increases as material passes through the press.

The speed of the press is adjusted automatically in response to a sensor monitoring the thickness of the mat at the first pressure roll. The speed of the chain is regulated to maintain a fairly steady mat thickness. Even feeding of the press is essential to achieving effective water removal. FMP does not recommend using vibrating feeders or vibrating conveyors because they do not spread out wood/bark residues as desired.

Tests have shown that water drains more freely from mats of coarse sized particles. Unhogged bark with pieces less than 50 mm thick are preferable. Hogged residues are, of course, suitable.

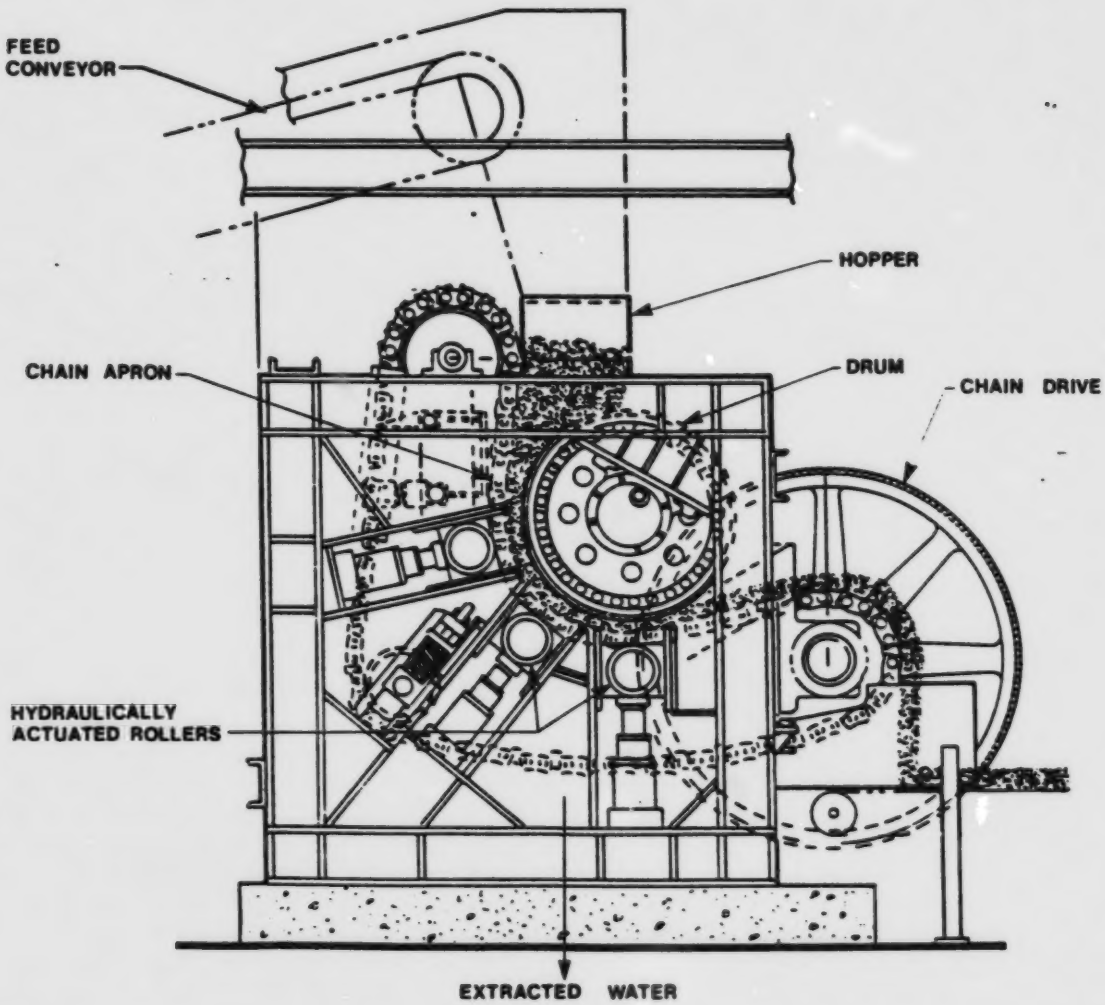


FIGURE III-2 FMP-RAUMA CHAIN PRESS

The press is not very sensitive to foreign material, being able to accept rocks etc. up to 100 mm x 100 mm x 100 mm in size without damage. The maximum size of tramp material before damage results is dependent on the mat thickness used.

The manufacturer's performance data for three sizes of press are given in Table III-3. Product moisture increases slightly with increasing feed moisture content. For example, Model 39 with hog fuel at 55% MC yields a product having 52% MC, while with hog fuel at 70% MC the product has a moisture content of 59%.

Information was gathered from sites of two installations of the FMP press on the B.C. Coast. One installation dewatering cedar bark could achieve a product moisture content of 45% with feed at in excess of 60% moisture content. The chain was the main maintenance item, with turnover needed after one year and replacement needed after two years of use. The side plates on the press were replaced annually. The second installation, MacMillan Bloedel at Powell River, uses one unit for dewatering hog fuel, which contains bark from the hydraulic debarker (80% MC). The press was found to operate reliably with product at 56% moisture content. A major overhaul is done on the press every 4 - 5 years. A spreader is used to achieve a uniform mat thickness, which is believed to be the reason for the units' good reliability.

3. Saalasti Oy

The roll press made by Saalasti Oy and sold under the name Bark Master dewaters bark and wood residues using pressure developed between an inner powered roller and an outer unpowered perforated drum (Figure III-3). Material is fed to the upper end of the press between the roller and the drum by a feed screw. Expressed water drains out through conically drilled holes in the drum designed to prevent plugging. The drum and inner roller are at a 10° - 15° decline causing the wet feed to tumble forward along the drum and to be pressed 4 - 5 times before being discharged. The material typically remains in the press for 2 - 3 minutes and is in the nip between the drum and the roller for about one minute.

The drum is supported on two support rings, each of which run on two rolls in a bogie. The support ring and roller running surfaces are covered to protect them from dirt, bark, effluent and other materials which would cause increased wear.

The pressure in the nip of the roller is created and regulated by a hydraulic system. The load in the nip is typically 125 t/m of roller length. The axis of the drum and the roller converge in the direction of material flow, causing a narrowing of the nip and greater pressure in this direction.

TABLE III-3 PERFORMANCE AND CAPACITY DATA FOR THE FMP-RAUMA CHAIN PRESS WITH HOG FUEL

	MODEL		
	27	39	51
Feed rate (dry t/h)	6.8	9.0	11.3
Feed moisture content (%)	60	60	60
Product moisture content (%)	54	54	54
Power Requirement			
kW mech	30	45	55
kWh/dry t	4.4	5.0	4.9

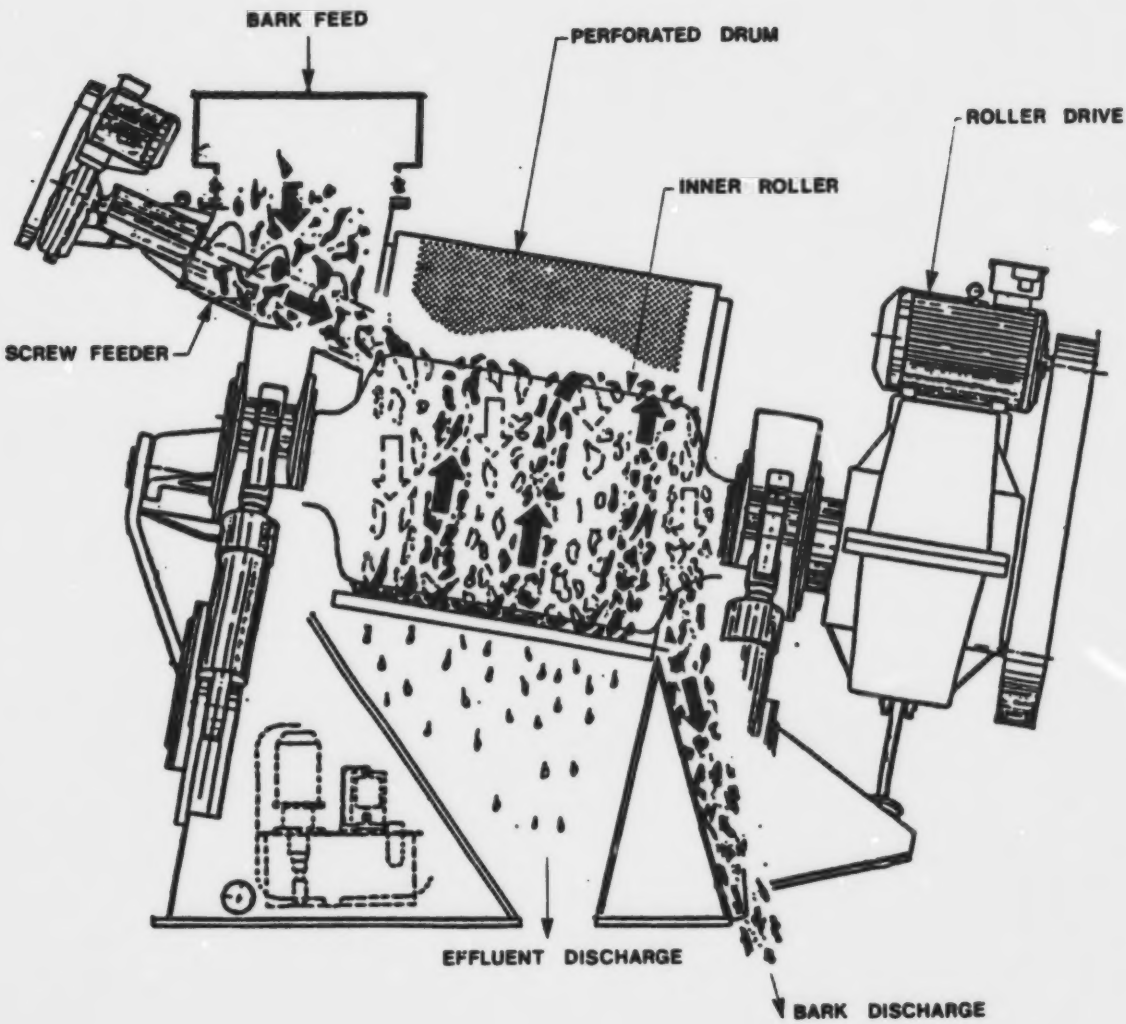


FIGURE III-3 SAALASTI-OY ROLL PERFORATED DRUM PRESS

When dewatering bark, hogging for size reduction is not normally required. Stringy bark may be the exception to this, but no experience with such feeds has been reported. The Bark Master press is relatively insensitive to foreign material, being able to accept an occasional rock 200 mm x 200 mm x 200 mm in size or tramp metal 50 mm in diameter x 600 mm long.

The discharged product typically has a moisture content of 50 - 55% wet basis irrespective of the moisture content of the feed. Data from a large number of tests using a Bark Master 83 at Western Pulp Partnership Ltd.'s Port Alice mill (Figure III-4) show that bark from Western Hemlock and Western balsam fir can be pressed to an average moisture content of 50.5% from 66%. The moisture content of the product was found in these tests to increase from 46% at a mat thickness of 2 cm to 52% at a mat thickness of 12 cm. The moisture content of the product increased from 46.5% at a flow of 2.5 dry t/h to 52% at a flow of 13 - 15 dry t/h. Typical operating data are summarized in Table III-4.

Information was obtained on the operating performance of Bark Master presses installed at the Port Alice and Squamish mills of Western Pulp Partnership Ltd. Two Model 83 units are used at Port Alice, while one is used at Squamish. The press at Squamish has performed well, yielding an output moisture content of near 50% for bark feed from a hydraulic debarker (70% moisture content). The unit developed cracks in the drum. The drum design has since been changed to avoid the structural problems encountered with the Model 83 drums. The Port Alice mill has two Bark Master 83 Model 2 presses for dewatering bark from the hydraulic debarker. The units reduce feed moisture from 67 - 72% to 55% on average. Costs for maintenance have been estimated for each unit to be:

- $ 60,500 every 2 years for repairs to drums, roll, shafts etc. (labour and material);
- $ 3,000/yr for cleaning drum holes;
- $ 500/yr for alignment of roller.

Hard surface drums were supplied for both units, but one has been replaced with a softer thicker steel and with tapered holes to reduce operating costs and reduce the cracking problem.

4. Enso Gutzeit Oy

Enso Gutzeit Oy manufactures a roller press for dewatering wood and bark on a continuous basis (Figure III-5.)

Wet feed is distributed evenly across the face of the roll by a screw conveyor. The powered drum draws the wet material between

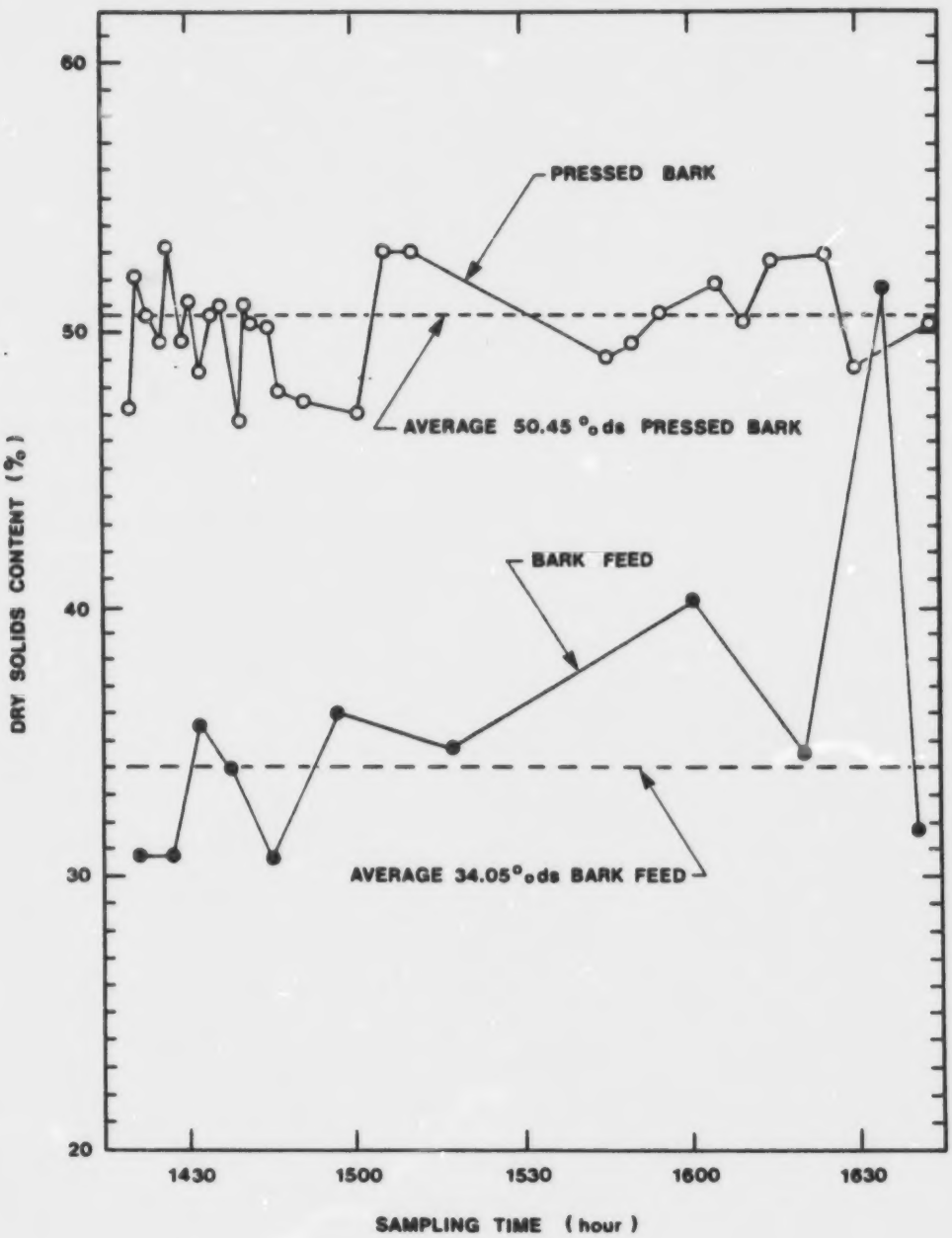


FIGURE III-4 TEST RESULTS FOR WESTERN HEMLOCK AND WESTERN BALSAM FIR DEWATERED IN A SAALASTI-OY PRESS

TABLE III-4 PERFORMANCE AND CAPACITY DATA FOR THE SAALASTI OY BARK MASTER PRESS WITH BARK

Feed rate	(dry t/h)		8 - 11	
Feed moisture content	(%)	58	60	85
Product moisture content	(%)	55	56	56
Power Requirement				
kW		55		
kWh/dry t		5.6		

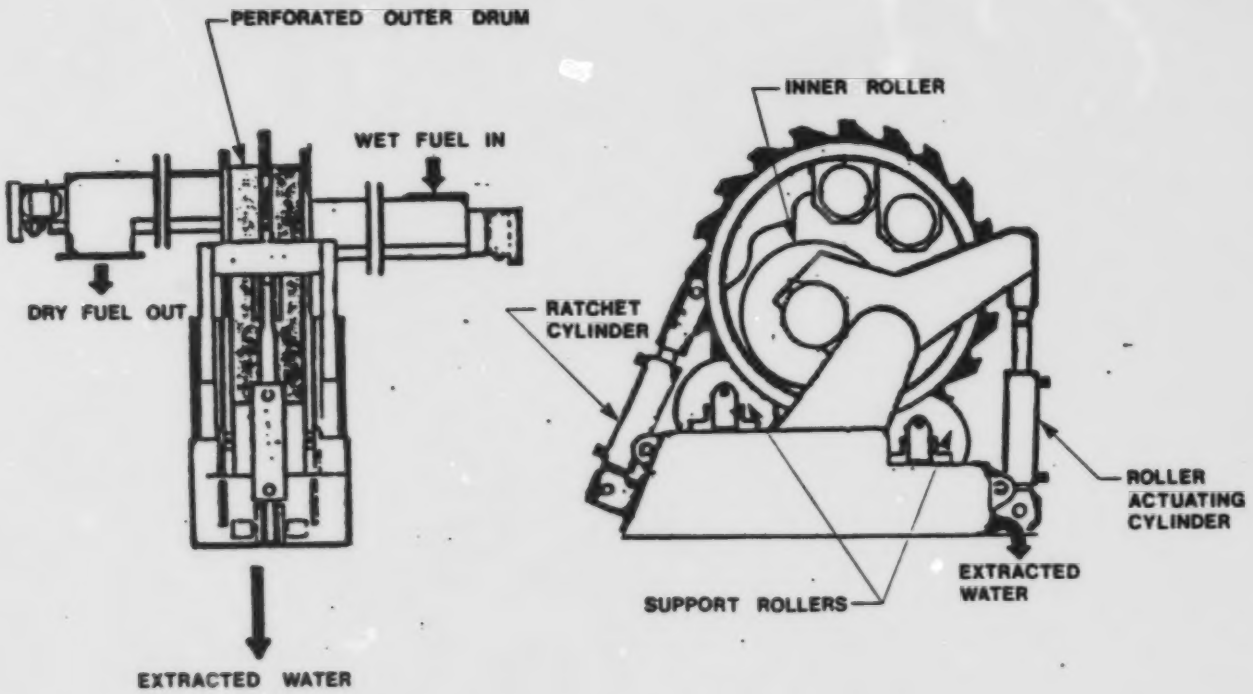


FIGURE III-5 ENSO GUTZEIT DRUM PRESS

itself and the inner roller, exposing the material to high pressure. Expressed water passes out through holes in the drum. The roller and drum are designed so that the material is under pressure for about 90° of rotation. After leaving the roller nip the material remains on the inner surface of the drum until it is scraped free and falls onto an outfeed screw conveyor. The drum is rotated in increments by the action of a ratchet drive, while the inner roller is unpowered, and rotated by the frictional force developed by the material under pressure.

The speed of the drum is controlled by varying the rate of movement of the hydraulic cylinder used to drive the ratchet.

As with the Saalasti Oy roller presses, the Enso Gutzeit press is not very sensitive to foreign material. Rocks to 75 mm diameter and tramp metal to 38 mm diameter can be tolerated by the 1400 x 500 model, while rocks to 100 mm diameter and tramp metal to 50 mm diameter can be tolerated by the 1700 x 750 model. The infeed and outfeed conveyors for these units must be sized according to the material being pressed.

Test data for the press are not available for specific wood/bark residues. Data from the manufacturer for bark are given in Table III-5.

No data could be obtained from users of the Enso press to report on operating and maintenance experience for the press.

5. S.W. Hooper & Co. Ltd.

The Hooper press can be used to dewater wood and/or bark either hogged or unhogged at a rate of up to 28 m^3/h (loose). The press uses a reciprocating ram and pressing beam to dewater material cyclically on a batch basis (Figure III-6). The capacity of the unit on a weight basis depends on the density of the feed.

Wet feed enters a batch feed hopper which is designed to hold the material that is to be pressed. A level switch is used on the feed hopper to prevent it being overloaded. When the previous press cycle has been completed and the feed hopper is full, the press ram retracts to its start position. This allows material to enter the press section in preparation for a new press cycle. The press ram advances on the new material, pressing it into the press chamber until the hydraulic pressure has increased to 12.06 MPa; this is equivalent to a pressure on the material at the face of the ram of 2.1 MPa. A press beam, pivoted at the front of the press chamber and actuated by a hydraulic cylinder at the discharge end, moves downward as the press ram advances, developing sufficient back pressure to prevent material from moving out of the discharge end, and to assist dewatering. When

TABLE III-5 PERFORMANCE AND CAPACITY DATA FOR THE ENSO GUTZEIT ROLL PRESS WITH BARK

	MODEL	
	1400 x 500	1700 x 750
Feed rate (dry t/h)	2.2	3.8
Feed moisture content (%)	55 - 70	
Product moisture content (%)[a]		
Spruce	55 - 60	55 - 60
Pine	50 - 55	50 - 55
Birch	45 - 50	45 - 50
Power Requirement		
kW mech	27	41
kWh/dry t	12.3	10.8

[a] varies with species

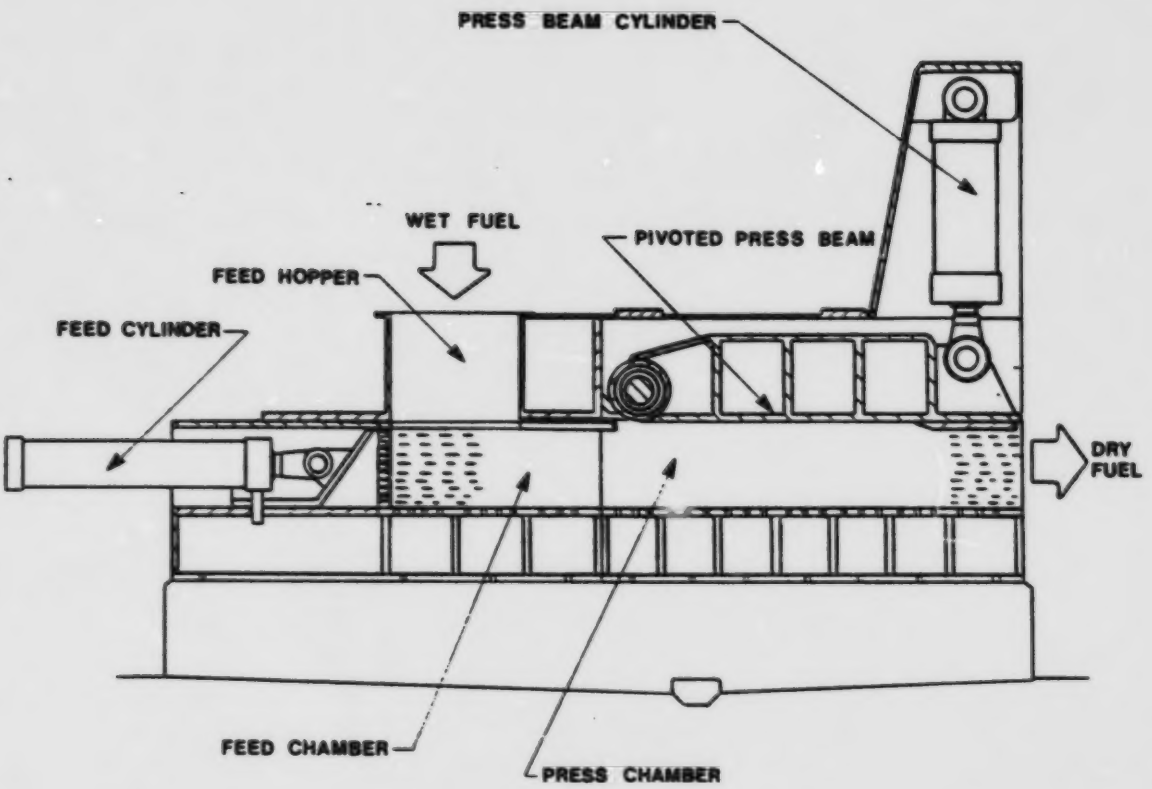


FIGURE III-6 HOOPER RAM PRESS

the hydraulic pressure in the ram has reached the upper limit of 12.06 MPa and after a controllable time delay, the press beam pressure is released and the beam itself is allowed to float on the compressed material. This action reduces the back pressure on the material in the press chamber, allowing the ram once again to advance and to move material to the discharge end of the chamber. At the end of its stroke, the ram reverses direction to return to start a new press cycle.

Water exits the press chamber through five perforated faces: two side walls; floor; feed ram; and discharge opening. The press beam forming the top of the chamber is not perforated.

The ram cycle time can be varied to accommodate more or less material, however, it typically falls between 13 and 17 seconds. The press comes from the factory set for a cycle time of 15 seconds and a dwell time at peak ram pressure of 3 seconds.

The water capacity of the Hooper press is greater for hog fuel than for bark, reducing the moisture content to 45% for hog fuel and to 50% for bark. The throughput capacity of the press on a dry weight basis varies with the density of the feed, but the volume capacity remains constant. The performance of the unit with bark is given in Table III-6.

The feed to the press need not be hogged if it will feed in the chute (450 mm x 600 mm) and the press properly. Uniform feeding across the feed chute also is of little concern because of the batch operation of the press.

The press is the least sensitive to damage by foreign material of the commercial presses available. Since the ram hydraulic system incorporates a pressure limit sensor to control operation, protection against damage from jamming of material and the ram during pressing is provided.

Personnel at the ITT Rayonier mill in Hoquiam, Washington had the following comments on the Hooper press installed and used for dewatering bark:

- the moisture content was reduced from 65% to 55%;
- problems were encountered with plugging of the feed and with overheating of the hydraulics;
- drain holes need to be cleaned every 6 months;
- modifications were made to increase the capacity of the feed-side hydraulics, add an oil cooler and strengthen structural ports.

TABLE III-6 PERFORMANCE AND CAPACITY DATA FOR THE HOOPER PRESS WITH BARK

Feed rate	(dry t/h)	5.5[a]
Feed moisture content	(%)	55-70
Product moisture content	(%)	50
Power Requirement		
kW mech		58
kWh/dry t		10.5

[a] Based on volume rate of 28.0 m^3/h and density in the press chamber of 200 dry kg/m^3

With these changes the unit works satisfactorily. Another unit was used at the ITT Rayonier mill in Port Angeles, Washington. Maintenance problems were encountered with:

- plugging of feed;

- breakdown of feed-side hydraulics.

For best performance, changes were needed to the cycle timing whenever the feed changed. The press at the mill was shut down in 1982-83, reportedly because of the operational and maintenance problems encountered.

6. Sunds Defibrator Ltd.

Sunds Defibrator Ltd. manufactures a conical screw feeder for feeding wood chips under pressure to the preheater in a TMP process. This unit can be equipped with a perforated throat and inlet housing for use of the equipment as a dewatering press.

Wet fuel enters through the feed chute into the inlet housing (Figure III-7). Material is carried into the tapered section of the screw and compressed, forcing water out and through the surrounding perforated wall. A variable plug restrictor is installed at the discharge end of the screw for control of pressure in the compression section. The back pressure created by the restrictor is regulated to compensate for variations in the properties of the material. The press screw is driven by an electric motor through a speed reducer to achieve a screw rotation rate of 45 RPM.

Two sizes of the press are available (Table III-7). The product from the press has a moisture content of typically 52%, independent of the moisture content of the feed.

Rocks and tramp metal small enough to fit between the flights on the screw and not touch the wall of the throat can be handled in the press. The ability of the press to handle foreign material in actual pressing situations is not known. Most experience with the press has been with clean wood chips.

7. Stake Technology Ltd.

Stake Technology manufactures a pressure feeder for wood residues that has seen commercial use for feeding of pressurized gasifiers and other biomass conversion systems. The company conducted tests with a prototype version of the feeder modified to dewater bark and hog fuel. This work was conducted under the ENFOR program (ENFOR Project C-6).

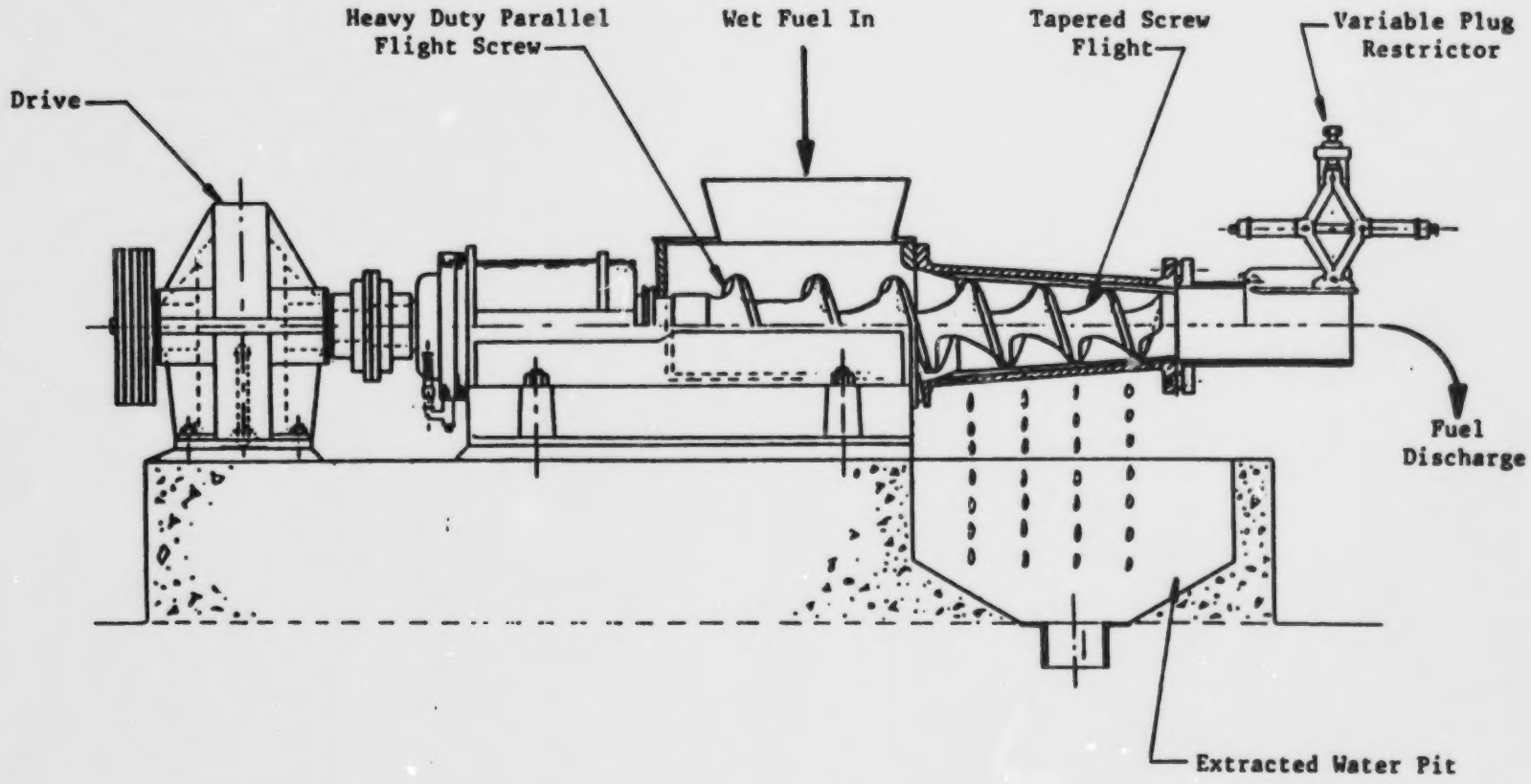


FIGURE III-7 SUNDS SCREW PRESS

TABLE III-7 PERFORMANCE AND CAPACITY DATA FOR THE SUNDS DEFIBRATOR PRESS WITH BARK

		MODEL	
		M-71	M-70
Feed rate	(dry t/h)	1.5	3.8
Feed moisture content	(%)	55 - 70	55 - 70
Product moisture content	(%)[a]	52	52
Power Requirement			
kW mech		37	75
kWh/dry t		24.7	19.7
Screw diameter	(mm)	250	430

The prototype dewatering press (Figure III-8) consists of a screw operating inside a sleeve which reciprocates at 300 cycles/minute. A choke at the discharge provides back pressure to material moving through the perforated dewatering zone. Water expressed from the feed leaves through the perforations and drains out the bottom of the press.

From tests done as part of the ENFOR project it was demonstrated that wet bark could be dewatered to a moisture content as low as 45%. Various choke sizes were used to investigate their affect on performance. For a 76.2 mm choke, which yielded best results, the electrical energy requirement was 13 - 25 kWh/t, depending on the water removal rate.

A full-size prototype was installed and tested in 1987 at the MacLaren Industries Kraft Pulp Mill in Thurso, Quebec. The design was based on Stake's commercial feeder design and tested at the mill to determine performance with hog fuel. The feed for the unit is limited to a top size of about 50 mm. The commercial prototype was tested over a six week period ending in November, 1987. The press yielded a product moisture content of 50 - 52%, wet basis with feed of over 60% moisture content. The press piston operated at 250 cycles/minute over a 127 mm stroke. Moisture was expressed through a slotted barrel having an overall length of 1118 mm. The press was rated at a production rate of 9 t/h and utilized a press section 254 mm in diameter. A report on the results of the tests has been prepared by Stake Technologies (Ing, 1988).

8. Black-Clawson Kennedy

This company developed a prototype bark press and did some testing of it in 1986. Problems were encountered with this unit. Further research at a laboratory scale is being done to develop a press for wood residues, but information is not being released at this time (Gay, 1988).

9. Centre De Recherche Industrielle Du Quebec (CRIQ)

CRIQ has developed and patented a press for dewatering fibrous suspensions. It has been used to dewater primary clarifier sludges, groundwood, thermomechanical pulp, chemithermomechanical pulp, chemical pulp, masonite pulp, cotton linters and rejects from pulping processes. The press consists of a drive rotor positioned coaxially in a smooth-walled housing. Up to four perforated channels can be placed around the circumference of the rotor. The rotor turns counterclockwise causing compacting pressure to be developed by the frictional force between the housing at the material in the dewatering channels. Feed enters at the 3:00 position, travels approximately 270° and is discharged

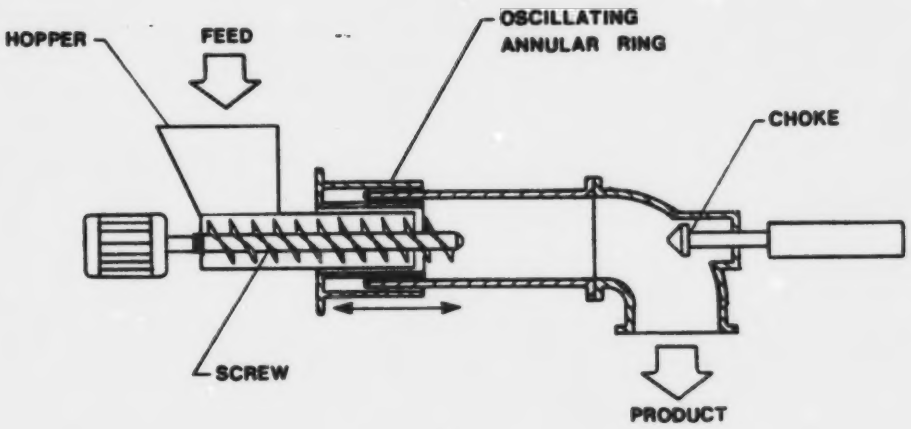


FIGURE III-8 STAKE TECHNOLOGY BARK PRESS

with the aid of a doctor blade placed against the channel bottom. The back pressure on the material can be adjusted using a restrictor plate on the discharge.

The CRIQ press has been commercialized and is being marketed by Kamyr under the trademark Ring Press. Presses are installed in Mobile, Alabama, Memphis, Tennessee and Hull, Quebec for pulp and paper sludge and cotton linter.

Some trials of the Ring Press with bark have been done by CRIQ. In these tests, product moisture contents reduced to as low as 50%, wet basis. Further details of the results of tests with wood residues were not made available. Various units are available at CRIQ for testing purposes, these ranging in size from 457 mm to 2286 mm in diameter.

B. Other Bulk Materials

An extensive review of published literature and trade directories was done to search for dewatering presses which might be suitable for wood residues. Dewatering presses are available commercially for a wide range of bulk materials such as sewage sludge, chemical products, fermentation byproducts, metallic compounds, food products, etc. Presses for dewatering of such products generally fall into one of the following categories:

- belt press;
- filter press;
- screw press;
- roll press;
- baling press.

None of the many presses reviewed in this study that are now used commercially for dewatering materials other than wood residues were considered candidates for adaptation to this use. However, it was not possible or practical to contact every manufacturer of presses to determine if the design had been tested with wood residues or might be suitable for such feed materials. Consequently, potentially suitable presses now used for other purposes may have been overlooked.

IV. BACKGROUND AND THEORY OF DEWATERING

A. Review of the Literature

A computerized search of the published literature was conducted for the past ten years to identify work that had been done on dewatering of biomass, food products, agricultural products or other materials. Relatively few articles were found in the data bases that were searched:

- Engineering Index;
- NRC publications;
- Engineering Index, Engineering meetings.

However, some of the articles found dealt specificially with dewatering wood/bark and, thus, were valuable to the work undertaken in this project.

1. Dewatering Processes

A series of articles on mechanical dewatering of solid and chipped wood have been published by Haygreen (1981, 1982) and Liu and Haygreen (1985). These reviewed the benefits of mechanical dewatering and present theory and laboratory test data for dewatering of solid wood and chips in a platen press.

Haygreen (1981) summarized the disadvantages of using wet wood/bark fuels:

- the available heat per pound of wet fuel is less;
- the efficiency of a boiler is reduced because of the energy required to vapourize the water present in the fuel (Figure IV-1).
- the capacity of a boiler is reduced because of the greater flue gas volume created by evaporation of wood moisture and of the lower efficiency of fuel conversion (Figure IV-2);
- the performance of particulate removal equipment may be reduced because of the greater stack gas flow rate created by evaporation of wood moisture. This depends, of course, on the basis for the boiler design;

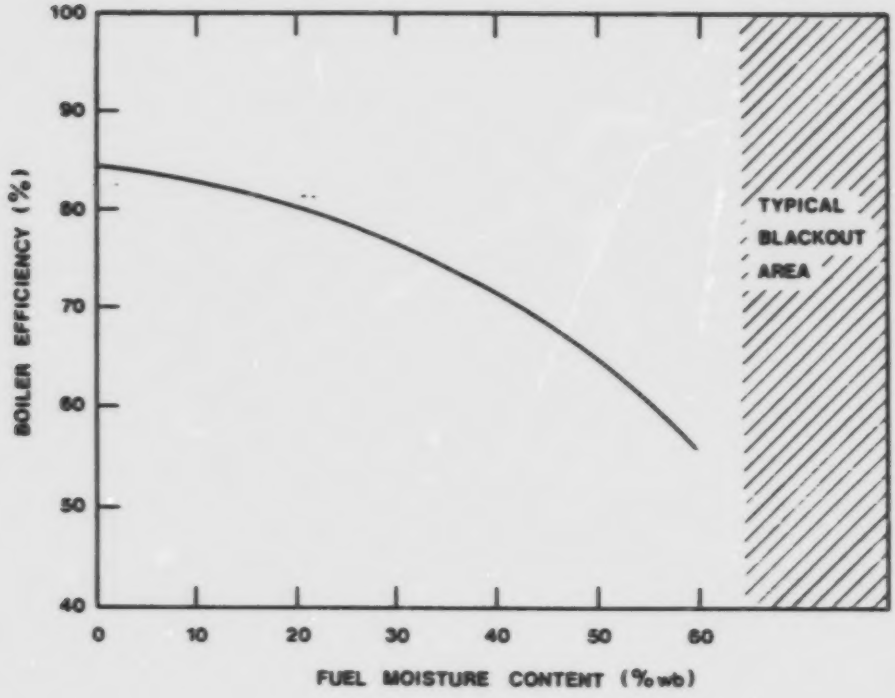


FIGURE IV-1 EFFECT OF FUEL MOISTURE CONTENT ON BOILER EFFICIENCY

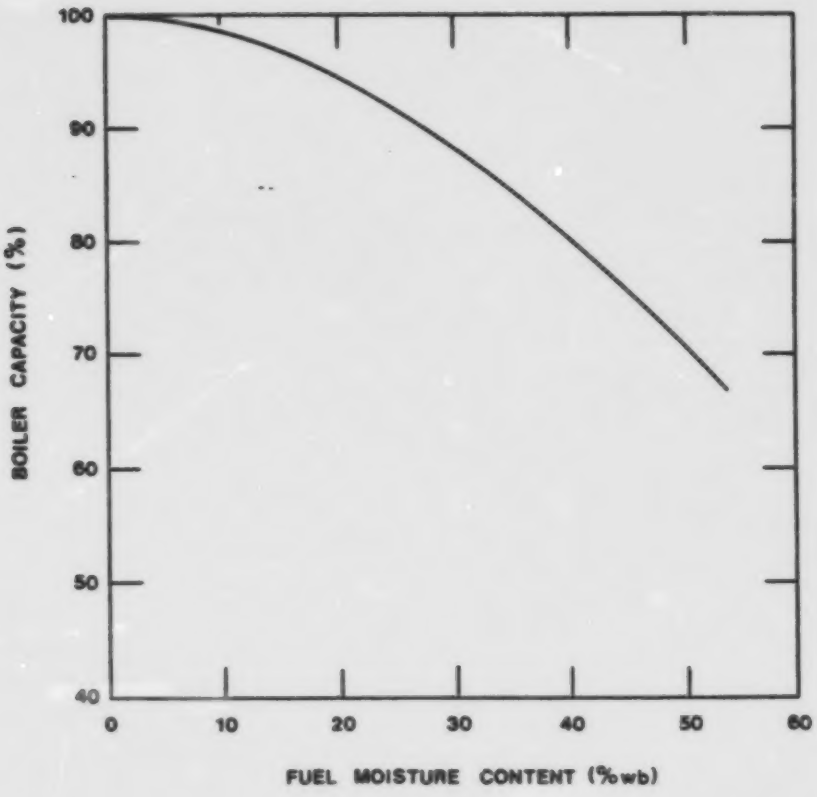


FIGURE IV-2 EFFECT OF FUEL MOISTURE CONTENT ON HOG FUEL BOILER CAPACITY

- the variability of fuel moisture makes control of boiler operation more difficult and tends to result in less than optimum boiler performance.

These disadvantages are fairly common knowledge. The disadvantages of wet fuel for a specific boiler or other combustion system may include some or all of the above depending on the boiler design parameters.

Haygreen (1981) studies dewatering of idealized chips cut to specific dimensions. The specimens studied theoretically and experimentally were sized to 25.4 mm along the grain, 25.4 mm width and two thicknesses: 12.7 mm; and 25.4 mm. A theoretical relationship for moisture content as a function of initial specific gravity, volumetric compression and physical characteristics of the wet material was developed using the following assumptions:

- the volume of air and water expelled by compression of the wood are in the same proportion as originally existed;
- no water is removed by compression from the wood substance; only free water in the lumen is removed;
- no compression of the wood substance occurs;
- the moisture content of the wood substance remains constant at 30%, dry basis;
- the specific gravity of the wood substance is 1.5 (dry wood-wet volume);
- the specific gravity of water bound in the wood substance is 1.05;
- no water loss occurs until the wood has been compressed a percentage S.

The resulting relationship for moisture content reduction from compression is:

$$\Delta MC = -(C - S)\left(\frac{0.01\,MC - 0.30}{1 - 0.95\,SG}\right)$$

where,

ΔMC = change in percent moisture content, dry basis

C = percent volumetric compression
100((initial volume-compressed volume)/initial volume)

MC - initial moisture content of dry basis

SG - initial specific gravity, dry weight and green volume

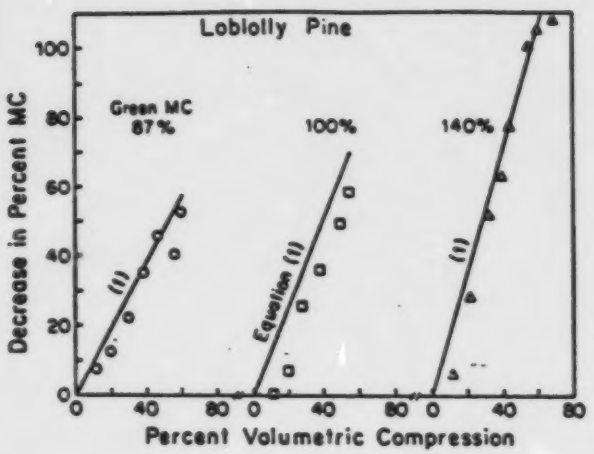
S - percent compression when significant water loss begins

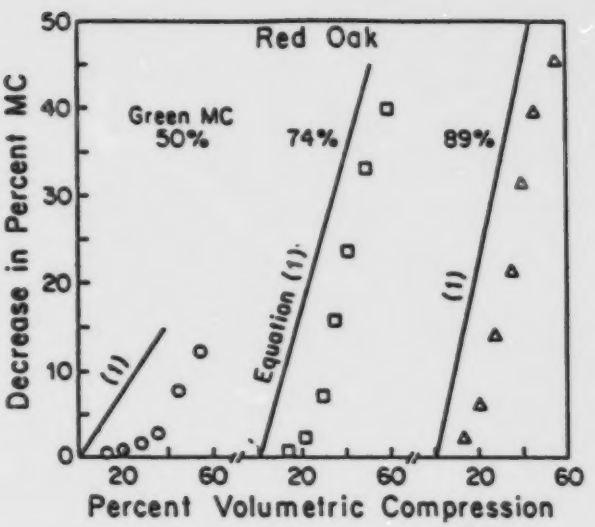
The moisture loss predictions using the theoretical equation were found to be somewhat higher than the results obtained in laboratory tests of solid wood samples (Figure IV-3). The rate of moisture loss, however, was found to be similar to the predicted value.

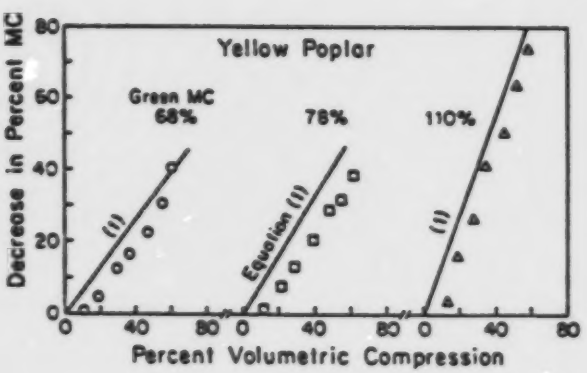
Haygreen (1982) presents results of laboratory tests using solid wood cubes and chip mats in a platen press under various conditions of initial moisture content and volumetric compression. The moisture content of the solid wood samples as a function of applied pressure is shown for tests with loblolly pine, red oak and white birch. The mechanical work required to compress solid wood samples was found to vary with wood species and percent compression and used with the data for moisture reduction to identify the percent compression which minimized energy input per unit of water removed. The tests on chip mats were done with an enclosed 139.7 mm diameter test cell at pressures up to 89.57 MPa using 0.91 kg samples. The samples were prepared by chipping solid wood with some bark to two sizes: small chips - passing a 12.7 mm screen; and large chips - retained on a 12.7 mm screen. Figure IV-4 shows the results form tests with chips without bark and with bark: bark fractions by weight - balsam fir 9%; red pine 11%; aspen 15%. Only a minor amount of drying was observed above 27.6 MPa. Tests of the effect of the duration of the pressure showed that time is a factor in the extent of water removed. About 15 - 17% more water was removed holding the pressure for 45 seconds and further water loss occurred if the pressure was held for 100 seconds.

Further laboratory testing of dewatering of wood chips in a platen press has been done by Liu and Haygreen (1985), specifically regarding the time-dependence of dewatering. The same size of dewatering test cells was used as in the case of Haygreen (1982). Seven hundred grams of pulp chips (19.1 mm long x 6.4 mm thick) or hammermilled chips (8.1 mm long x 1.0 mm thick) were used in the tests at pressures from 3.4 MPa to 13.8 MPa. From the time pressure was reached, the tests were run for a compression period of four minutes. The studies included five species: aspen; balsam fir; jack pine; red maple and red oak.

The most rapid dewatering rate was observed in the first two minutes of pressing, with little observed after four minutes. Relatively little difference between the moisture content of small and large chips dried at different pressures (Figure IV-5). The







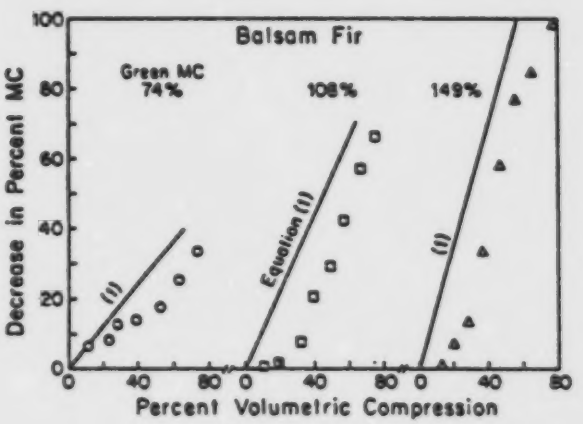
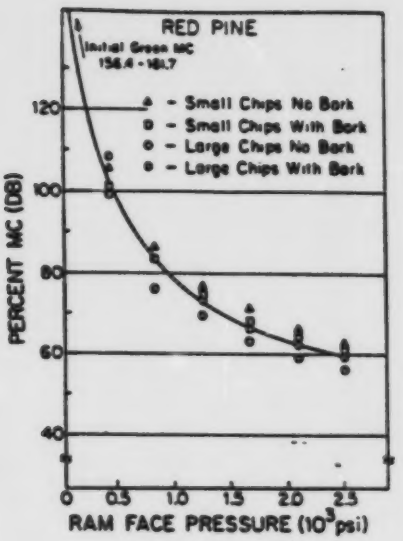
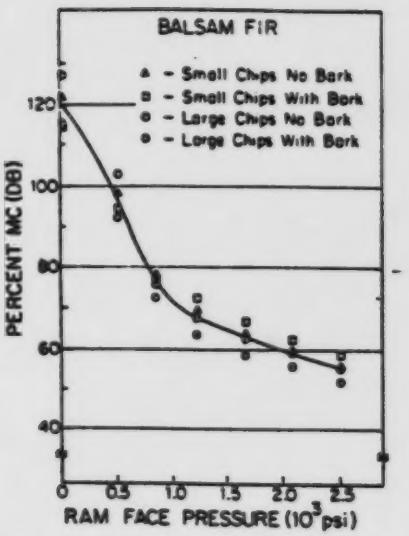


FIGURE IV-3 MOISTURE LOSS RESULTING FROM VOLUMETRIC COMPRESSION OF SOLID WOOD SAMPLES FOR FOUR SPECIES





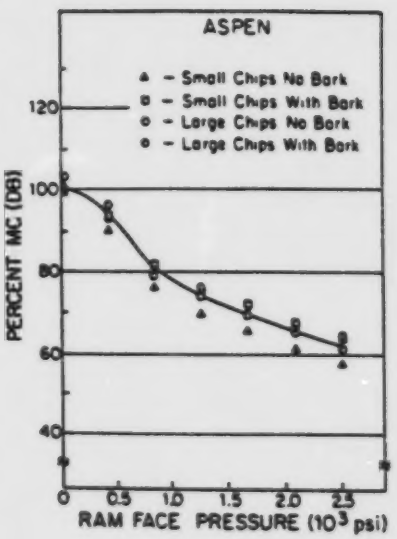


FIGURE IV-4 DRYING CURVE FOR WOOD CHIPS PRESSED TO 17.2 MPa (2500 psi)

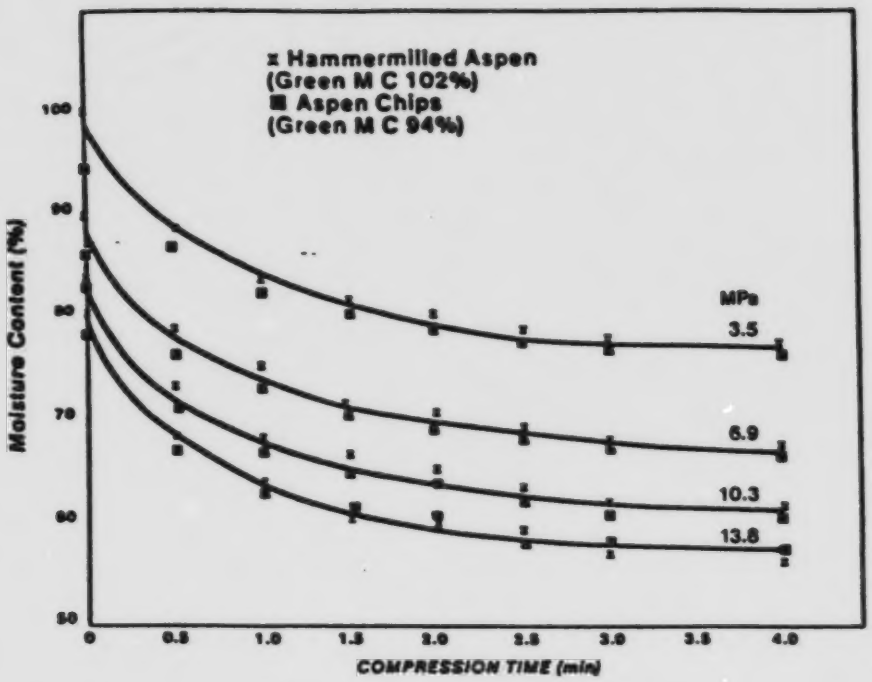


FIGURE IV-5 MOISTURE CONTENT AFTER REACHING AND HOLDING VARIOUS PRESSURES

moisture content had reached its lowest value after about three minutes of pressing. The minimum moisture content reached when pressing Aspen at 13.8 MPa (2000 psi) for four minutes was 57%, dry basis, or 36%, wet basis.

In his Doctorate thesis Wingate-Hill (1985) presents results of tests done on solid wood samples (20 mm x 20 mm x 60 mm) of *Pinus radiata, Aroucaria cunninghamic, Eucalyptus regnans and Eucalyptus abliqua*. The specimens were pressed in a platen press test rig with and without supports to prevent lateral movement. Exhaustive testing was done to determine the water removed for various initial moisture contents, pressures, species and compressive strain. Comparison of test data was made to that predicted using Haygreen's (1981) dewatering model and equation. Wingate-Hill concluded that the equation "does not predict moisture content reductions accurately for sapwood specimens caused by compression perpendicular to the grain". He found that the levels of saturation of the lumens with water increased significantly as the samples were compressed, contrary to the simplifying assumption made by Haygreen (1981) that saturation remains constant. This was concluded to be the main reason why the equation developed by Haygreen (1981) did not accurately predict moisture content reduction with compression. Moisture loss during compression perpendicular to the grain in the species tested increased with initial moisture content and the amount of compression and decreased with wood density (Wingate-Hill and R. Cunningham, 1984). This same reference noted that only small differences were observed between the two hardwoods and two softwoods, but large differences were observed between the two groups.

Haygreen and Steklenski (1985), University of Minnesota, conducted a project for the U.S. Department of Energy to develop a pilot scale dewatering press. This work was a scale-up of the laboratory tests done on dewatering of comminuted wood residues with a platen press. The press (Figure IV-6) was designed with a 30.48 cm x 30.48 cm x 1.2 m high press chamber oriented vertically. Compression of the material in the chamber was done from above with a ram capable of applying a pressure of 68.9 MPa. The ram could be closed in 35, 46 and 58 seconds when under load. The lower 30.48 cm of the sides of the press chamber were slotted or grooved to allow drainage of water out the bottom of the press. The pressing cycle was as follows:

- fill the press chamber wtih material;

- extend the ram until a preselected pressure is reached;

- hold this end pressure for a period of time;

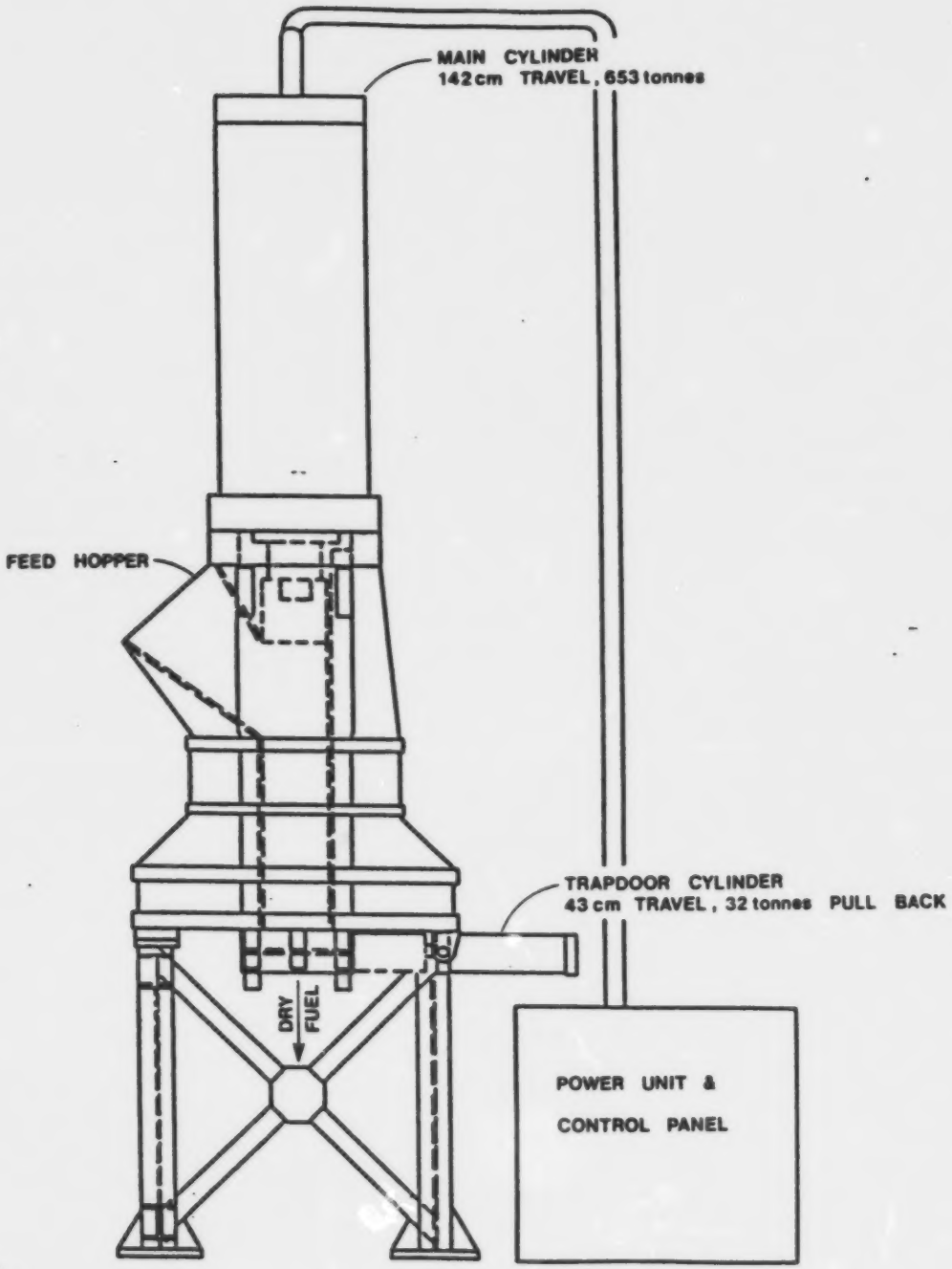


FIGURE IV-6 GENERAL SCHEMATIC OF THE USDOE/U OF MN COMPRESSION DRYING PRESS

- retract the ram;

- open the door at the bottom of the chamber and discharge material;

- repeat cycle.

The range of results obtained form a total of many test runs with chips less than 25.4 mm in size from bolts of aspen, paper birch, red pine, balsam fir, jack pine and some whole tree chips are shown in Figures IV-7 and IV-8. The main conclusions from the test program were:

Ram Face Pressure

For feed materials of typical densities and green moisture contents, a pressure of about 13.8 MPa is adequate for effective drying. Significant drying occurred between 13.8 and 27.6 MPa, but almost no additional drying occurred above 27.6 MPa.

Pressing Time

As a general rule, a pressing time of about one minute is most effective considering energy required and cost. A significant amount of additional drying resulting from pressing from one to three minutes, though little benefit was seen for drying beyond three minutes.

Initial Moisture Content/Species

There was a weak relationship between initial green moisture content and the final moisture content under any test conditions. Typically, there was a 2 - 5% higher final moisture content for each 10% increase in initial moisture content. Initial moisture content and density varies with wood species.

Chip Size

The presence of a normal amount of fines (up to 30%) in the feed does not adversely affect dewatering. Tests were not done to determine the effect of particle size on dewatering.

Charge Volume

The smaller the volume pressed, the lower the final moisture content under any pressing conditions. This improvement may not be advantageous in practical use of the press because of the reduction in press throughput that would result.

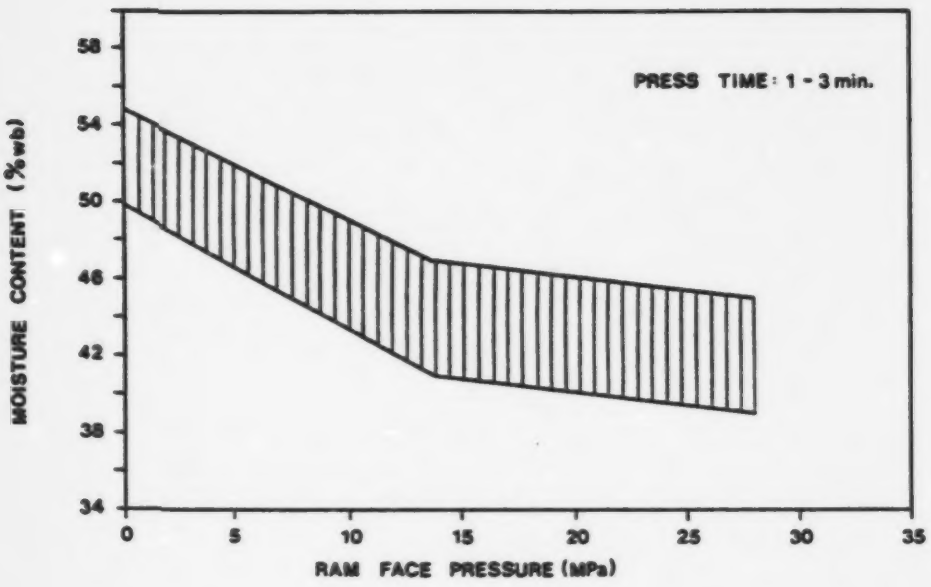


FIGURE IV-7 THE RELATIONSHIP OF FINAL MOISTURE CONTENT (RANGE) AND RAM FACE PRESSURE FOR INITIAL MOISTURE CONTENTS FROM 50 TO 55% AND PRESS TIMES FROM 1 TO 3 MINUTES

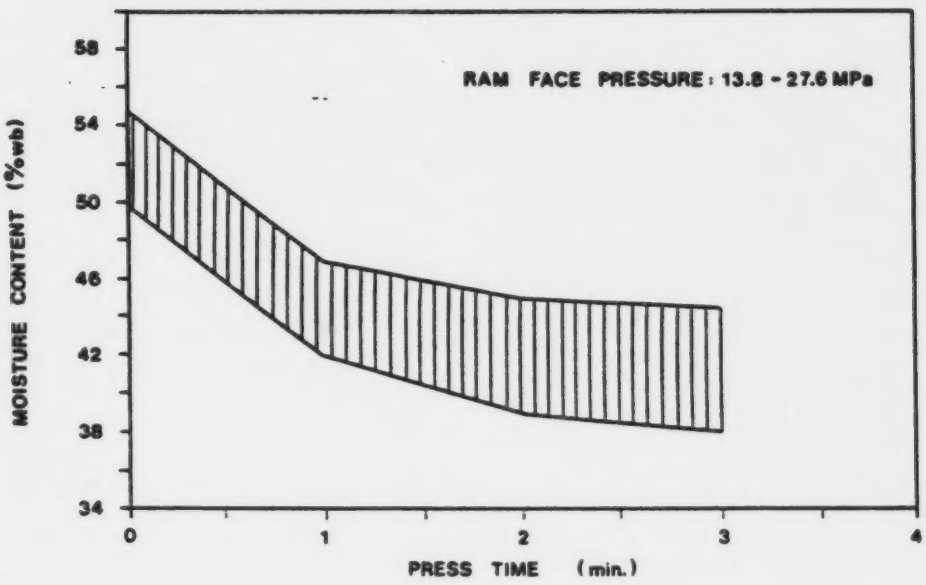


FIGURE IV-8 THE RELATIONSHIP OF FINAL MOISTURE CONTENT (RANGE) AND PRESS TIME FOR INITIAL MOISTURE CONTENTS FROM 50 TO 55% AND RAM FACE PRESSURES FROM 2000 TO 4000 PSI

Ram Face Configuration

A limited amount of testing done with a ram face that was raised in steppes towards the centre showed that 1 - 2% lower moisture contents could be achieved compared to a flat ram face.

Press Cost

The installed cost of a press capable of dewatering 8.1 ODt/h of hogged or chipped residues from 60%, wb to 40%, wb was estimated to be 750,000 (1985). The unit would cycle every 3 minutes using a 404 OD kg charge. The press would be driven by a 50 kW motor (6.2 kWh/dry t).

The study recommended that a prototype press be built and installed for testing in an industrial plant. Recommended design specifications for the prototype were also given.

Nyberg (1975) has suggested the use of a screw extruder developed by B.C. Research for dewatering of wood residues. The discharge moisture content of the extruder was indicated to be 35 - 45%, wet basis. Teixos Technology Corp. (1987) planned to adapt the B.C. Research extruder to dewatering at a throughput of 10 t/h. Some testing of the screw press was done at B.C. Research, but further work has not proceeded.

2. Economics of Dewatering

Hooper (1986) concluded that dewatering of bark in Canada has a good return on investment for feed having a moisture content greater than 55%, wet basis when using commercially available dewatering equipment. Data for the Hooper Bark Press was given:

Feed Bark Moisture (%)	Average Pressed Bark Moisture (%)
66 - 75	55
60 - 65	52
55 - 60	50

	Installed Cost ($ 1000)		
	2 Presses	3 Presses	4 Presses
Equipment and erection	225	340	450
Piping work	60	85	110
Building	35	45	60

Engineering	45	50	55
Total	365	520	676

Operating and maintenance costs, based on $ 8,280 h/year were estimated to be:

	($ 1000)		
	2 Presses	3 Presses	4 Presses
Power	12227 kW	18040 kW	23953 kW
Maintenance and operators	50	75	100

Pressing to reduce bark consumption only, i.e. rather than displace oil consumption, was concluded to generally not be economical.

Tsaros (1988) has compared the dewatering costs for four dewatering systems:

- Ingersoll-Rand Vari-Nip presses followed by rotary drum dryer;
- Ingersoll-Rand Vari-Nip presses followed by flash dryer;
- Sulzer Multi-Nip presses followed by fluidized bed dryer;
- Ingersoll-Rand Vari-Nip presses followed by multiple-effect evaporator.

The feedstock for the drying systems was peat at 92%, wet basis. The dried peat had a moisture content of 35%, wet basis for gasification. From a detailed cost analysis it was concluded that peat could be dewatered from 92% to 35% at a rate of 810.8 ODt/h for a cost of US $ 1.10/GJ based on utility financing. The plant analyzed was very large, benefiting from economies of scale.

Callas (1987) studied the economics of dewatering wood chips using a platen press of the same design as tested at a pilot scale by Haygreen and Steklenski (1985). The press was concluded to be not suitable for drying wood residues containing a large proportion of fine materials because of problems with plugging of dewatering slats in the press. Three systems were considered:

- dewatering of purchased wood chips from 60% to 40% for burning in a 22,700 kg/h boiler and displacement of fossil fuel;

- dewatering of previously unburnable residues from 68% to 45% and displacement of purchased wood chips;

- dewatering of wood chips from 60% to 40% to increase the output of a boiler 15%.

Based on the analysis of the selected case studies Callas (1987) concluded that use of mechanical dewatering to increase boiler capacity or to make wet residues suitable for burning were economically attractive. Dewatering of purchased residues did not look economically attractive, especially when the feed moisture content was below 55%, wet basis. The economic feasibility of mechanical dewatering was found to be very site specific.

B. Theoretical Model of Dewatering of Wood Residues

A model has been developed by Haygreen (1981) for dewatering of solid wood by compression. The assumptions used to formulate this model, as summarized in the previous section, are:

- the volume of air and water expelled by compression of the wood are in the same proportion as originally existed;

- no water is removed by compression from the wood substance; only free water present in the lumen is removed;

- no compression of the wood substance occurs.

Wingate-Hill (1985) gives a detailed derivation of the theoretical model.

The model for dewatering of solid wood is derived as follows:

Define the degree of saturation, S, of the cell voids, or lumen, within the wood:

$$S = \frac{\text{Volume free water in the void}}{\text{Volume free water + Volume air in the void}}$$

$$= \frac{Vw}{Vw + Va}$$

The value of S can theoretically range from 0, when no free water is present, to 1.0, when the void is full of water.

Relate the total volume of the wet wood to the volume of the components:

$$V_{\substack{wet\\wood}} = V_{water} + V_{air} + V_{\substack{dry\\wood}} + V_{\substack{bound\\water}} \quad (1)$$

where,

$V_{\substack{wet\\wood}}$ = total volume of wet wood

V_{water} = volume of free water in cells

V_{air} = volume of air in cells

$V_{\substack{dry\\wood}}$ = volume of wood, on a dry basis, in sample

$V_{\substack{bound\\water}}$ = volume of water present in the wood substance

Relate the volume of the components to their mass:

$$S(V_{water} + V_{air}) = V_{water}$$

so $$V_{water} + V_{air} = \frac{V_{water}}{S} \quad (2)$$

and $$V_{water} = \frac{M_{water}}{\rho_{water}}$$

where M_{water} = mass of water

ρ_{water} = density of free water

$$V_{\substack{dry\\wood}} = M_{dry}/\rho_{drywood} \quad (3)$$

where $M_{\substack{dry\\wood}}$ = mass of drywood

$\rho_{drywood}$ = density of dry wood substance based on wet volume

$$V_{\substack{bound\\water}} = \frac{X\, M_{drywood}}{\rho_{\substack{bound\\water}}} \quad (4)$$

where X = fraction by weight of water present in wood substance at fibre saturation

$\rho_{\substack{bound\\water}}$ = density of water in wood substance

Substitute equations (2), (3) and (4) into equation (1) to obtain:

$$V_{\text{wet wood}} = \frac{M_{\text{water}}}{\rho_{\text{water}} S} + \frac{M_{\text{dry wood}}}{\rho_{\text{dry wood}}} + \frac{X\, M_{\text{dry wood}}}{\rho_{\text{bound water}}} \qquad (5)$$

The volume of the wet wood is related to its mass and specific gravity (SG):

$$V_{\text{wet wood}} = \frac{M_{\text{dry wood}}}{SG\rho}$$

where $M_{\text{dry wood}}$ - mass of dry wood

SG - specific gravity of wood based on dry wood mass and total wet volume

ρ - density of water (6)

The mass of water is related to the moisture content on a dry basis as follows:

$$M_{\text{water}} = MC\, M_{\text{dry wood}} - X\, M_{\text{dry wood}} \qquad (7)$$

where M_{water} - mass of free water

MC - moisture content on a dry basis as a fraction

X - moisture content of wood substance on a dry basis at fibre saturation

Substituting (7) and (6) into (5) and rearranging to obtain an equation for moisture content on a dry basis (MC), gives:

$$MC = X + S\left(\frac{1}{SG} - \rho/\rho_{\text{dry wood}} - \frac{X\rho}{\rho_{\text{bound water}}}\right) \qquad (8)$$

The value of S and specific gravity vary as the wood is compressed. Since the weight of dry wood remains constant during compression, a relationship can be developed for the specific gravity at any time:

Let $C = (V_i - V_f)/V_i$

where V_i - initial volume
V_f - compressed volume

By mass balance,

$$V_i SG_i = V_f SG_f$$

so $$SG_f = SG_i/(1-C) \qquad (9)$$

Substituting equation (9) into equation (8) for any value of C gives:

$$MC = X + S\left(\frac{(1-C)}{SG_i} - \frac{\rho}{\rho_{dry\ wood}} - \frac{X\rho}{\rho_{bound\ water}}\right) \qquad (10)$$

Haygreen (1981) assumed the saturation of the lumen (S) remained constant during compression to obtain an equation for the change in moisture content achieved by compression. Substituting initial and final conditions into equation (10) gives:

$$\Delta MC = \frac{C(MC_i - X)}{\left(1 - \frac{\rho SG_i}{\rho_{dry\ wood}} - \frac{X\rho SG_i}{\rho_{bound\ water}}\right)} \qquad (11)$$

where $\Delta MC = MC_{initial} - MC_{final}$

He further substituted typical values for densities into this equation to get:

$$\Delta MC = \frac{C(MC_i - X)}{1 - 0.95\ SG_i} \qquad (11)$$

where the constants used are:

$X = 0.3$

$\rho_{dry\ wood} = 1.5$ g/cc

$\rho_{bound\ water} = 1.05$ g/cc

$\rho = 1$ g/cc

The tests done in this study with a platen press have demonstrated that S does not remain constant during compression. This has also been found by Wingate-Hill (1985). In this case, equation (10) must be used. However, this calculates moisture content as a function of saturation, which is in turn a function of compression, C. Therefore, to calculate the moisture content of the material at any level of compression, a relationship is needed for S as a function of compression, C.

Analysis of data from the platen press tests suggests that S(1-C) remains roughly constant during compression. If S(1-C) is a constant S*, then:

$$MC = X + \frac{S^*}{SG_i} - \frac{1}{(1-C)}\left(\frac{\rho S^*}{\rho_{dry\ wood}} + \frac{X\rho S^*}{\rho_{bound\ water}}\right)$$

Letting $k = \frac{\rho}{\rho_{dry\ wood}} + \frac{X\rho}{\rho_{bound\ water}}$ (12)

and $a = X + \frac{S^*}{SG_i}$ (13)

gives $MC = a - \frac{kS^*}{(1-C)}$ (14)

Equation (14) shows that if S(1-C) is a constant, the moisture content will decrease in proportion to 1/(1-C). The parameters a and k are constants and can be determined by either fitting the equation to experimental data, or calculation from equations (12) and (13).

Equation (14) can be simplified slightly by using initial conditions to determine an equation for the initial moisture content MC_i:

$$MC_i = a - kS^*$$

Therefore:

$$MC = MC_i - kS^*\left(\frac{C}{1-C}\right) \quad (15)$$

where k is calculated as per equation (12). This parameter takes into account the initial specific gravity of the wood as well as the densities of the wood substance and the water it contains.

V. METHODS AND MATERIALS

A. Presses Used for Testing

Three test presses were used to investigate the dewatering of wood and bark:

- platen press;
- ram press;
- opposed roller press.

A platen press configuration was selected because a wide range of test variables can be easily investigated independently and the application of press in a one-dimensional manner is perhaps most suitable for development of theory for understanding the dewatering process. A ram press was chosen because it is fundamental to the Hooper press and is a configuration widely used for the application of pressure on materials. The roller press test unit was selected because the Fulton Iron Works, Saalasti Oy and Enso-Gutzeit Oy presses dewater material by pressing it between two moving curved surfaces. There is also some use of the roller press concept in the Horton Chain Press.

1. Platen Press

The platen press test unit consists of a cylindrical shell with a perforated plate at the bottom and a solid circular ram at the top as shown in Figure V-1. Pressure was applied to the top of the ram by a hydraulically driven single-opening press. A bevel was machined around the perimeter of the bottom plate to provide an 8 mm gap for drainage of water as pressing proceeded. The ram is not attached to the upper platen of the press so it can be removed for placing of a charge in the pressure cell.

The procedures used for all test runs were as follows:

- weigh sample (800 - 1000 grams) of wet material and place in the pressure cell;
- place the ram on top of the material and record bed height;
- select the hydraulic pump to be used for the press. Two options are available:

  1. Low loading rate - low volume/high pressure pump throughout test.

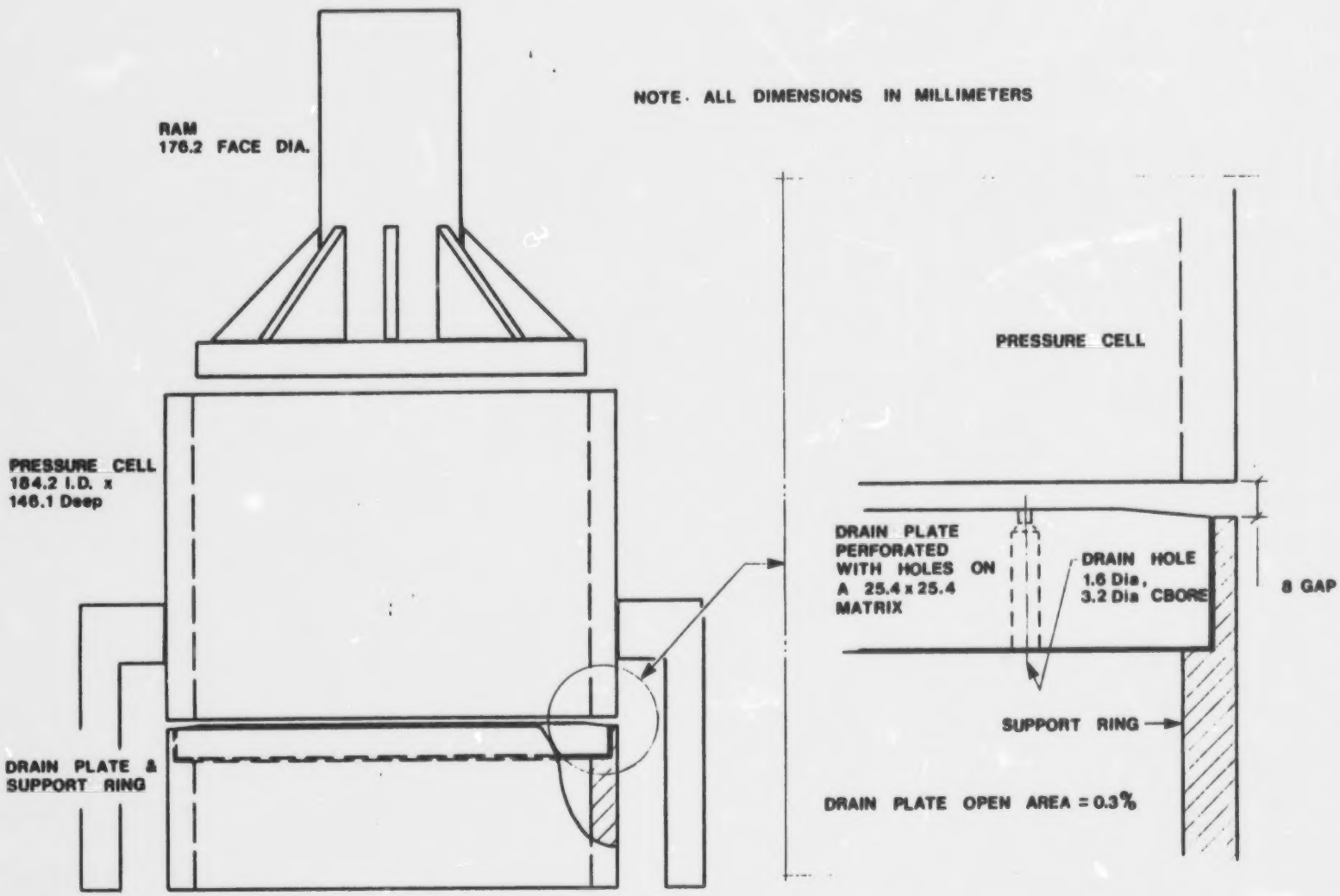


FIGURE V-1 PLATEN PRESS TEST UNIT

2. High loading rate - high volume/low pressure pump to a ram-face pressure of 4.7 MPa then a low volume/high pressure pump to the desired pressure.

- start the hydraulic press and apply a load on the ram;
- continue pressing until desired pressure is reached then hold pressure for 0, 1 or 2 minutes;
- record bed height and pressure;
- release pressure and measure bed height after spring back of the material in the pressure cell;
- remove ram, then remove sample and place the whole sample in a tray for determination of moisture content.

Figure V-2 shows typical low and high loading rate curves for the platen press. The difference between the times to pressure is relatively small because the flow to the hydraulic press cylinder is the same in both cases except for the early portion up to a ram-face pressure of 4.7 MPa. The times to reach the pressures used in the test program are given in Table V-1.

The whole sample pressed during tests was dried after the test was complete to determine its moisture content. The variation of moisture content throughout the sample by drying portions of the pressed material was not investigated. It was felt that the sample could be adequately characterized by determining the moisture content of the whole sample and that there would be little benefit to measuring the variability of moisture content at the physical scale being used.

2. Ram Press

The ram press used for tests was driven hydraulically using the same hydraulic pumps used for the platen press. Material is fed to the reciprocating cylindrical ram through a simple hopper and is pressed as it moves through a dewatering section, then the attached barrel or die (Figure V-3).

The pressure developed on the material at the face of the ram is dependent on the frictional force on the surface of the material in the dewatering section and the die. The working pressure of the press was varied during the experiments in two ways:

- the stroke of the ram was shortened to produce a longer extrusion and, correspondingly, a larger back-pressure;

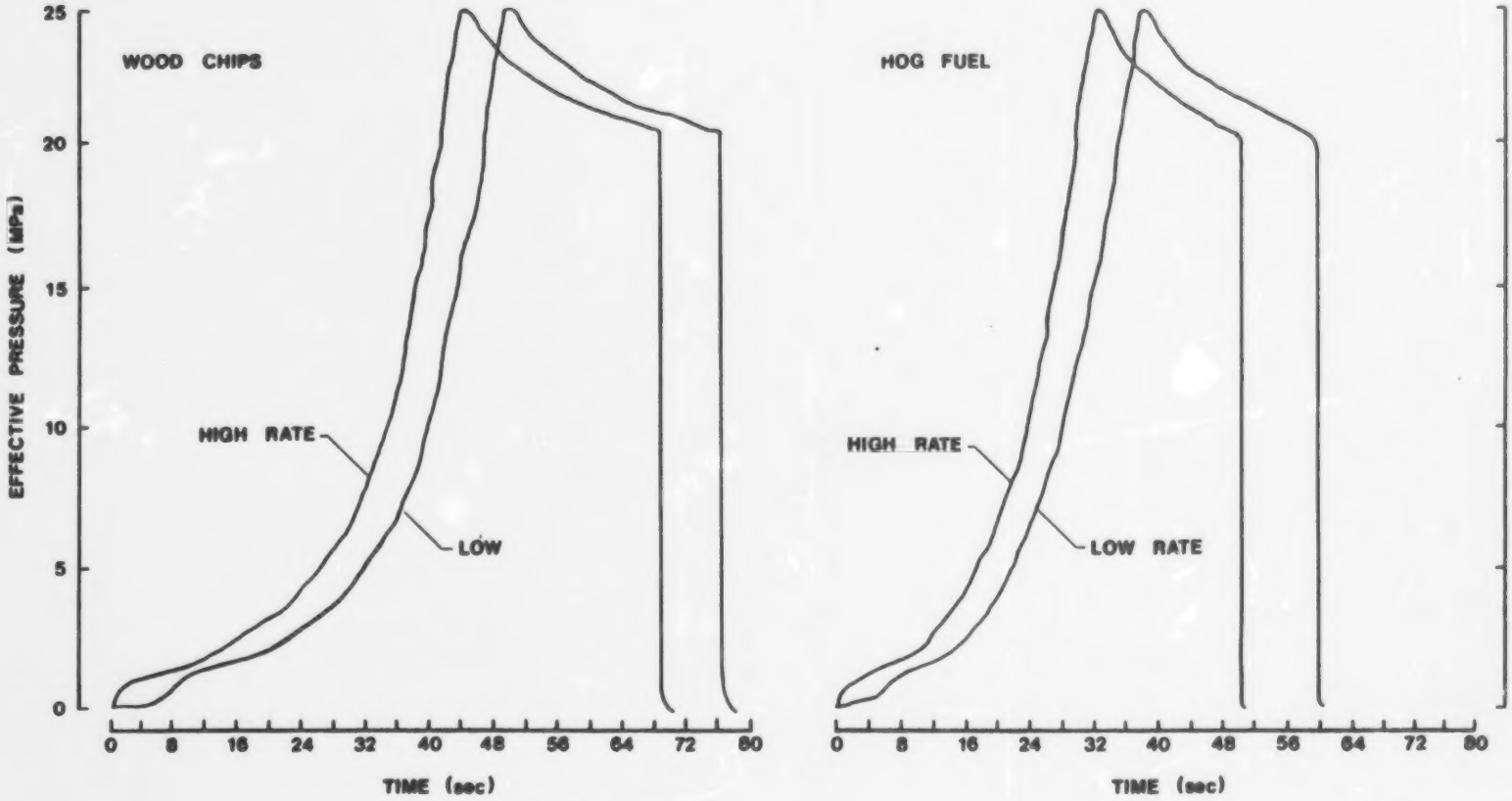


FIGURE V-2 TYPICAL LOADING RATE CURVES FOR LOW AND HIGH RATE TEST CONDITIONS

TABLE V-1 AVERAGE TIME REQUIRED TO REACH TEST PRESSURES FOR THE PLATEN PRESS

PRESSURE (MPa)	TIME TO REACH PRESSURE (SECONDS)			
	LOW LOADING RATE		HIGH LOADING RATE	
	CHIPS	HOG FUEL	CHIPS	HOG FUEL
5.13	31.5	21.7	28.6	18.4
9.97	39.4	27.3	35.6	23.9
15.10	42.9	31.1	39.4	27.5
19.94	45.8	34.0	42.3	30.2
25.07	48.5	36.7	45.1	32.8

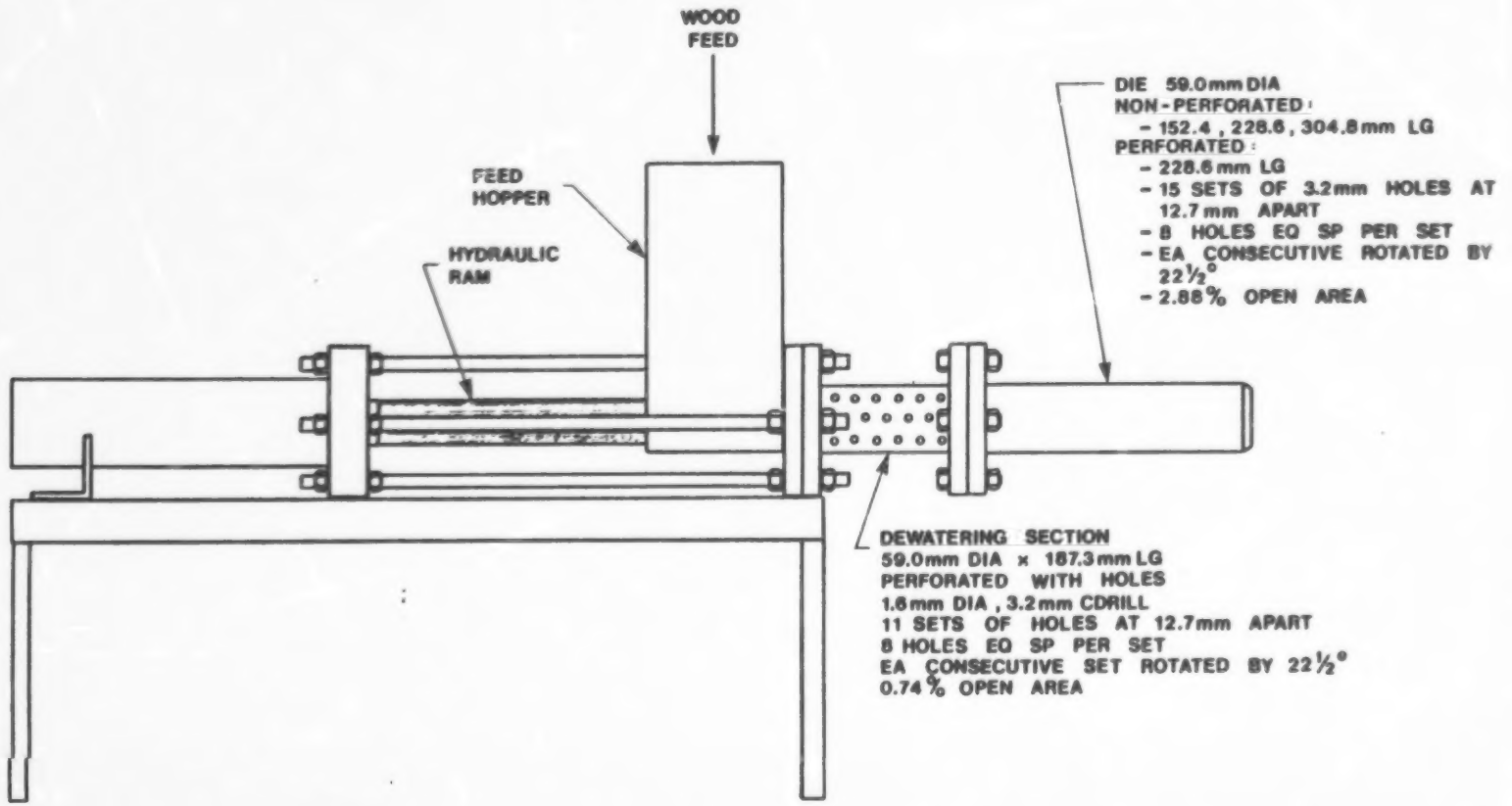


FIGURE V-3 RAM PRESS TEST UNIT

- a shorter die was used to shorten the length of the extrusion and reduce the back-pressure.

By using a combination of these adjustments the ram press could be operated at numerous pressure levels over a fairly wide range.

To determine the affect of the dewatering area on the produced moisture content, some tests were done using a perforated die attached to the end of the dewatering section.

The general procedure used for tests of the ram press was:

- add material in small batches to the feed hopper;
- cycle the ram at the maximum rate for the pressure applied. The cycle time varied with peak pressure and other conditions from 20 to 56 seconds per stroke;
- continue feeding material until the barrel is full and the ram pressure is consistent for each cycle;
- continue feeding and collect the discharged material for measuring its moisture content. Typically, 800 - 1300 grams of product were collected and dried to measure the moisture content.

3. Roller Press

A roller press test was developed using the hydraulic cylinder and a feed barrel to force material between opposed rollers (Figure V-4). The feed barrel was sized to be larger than the feed ram to minimize the back pressure developed before the material entered the rollers. Side plates were used on the lower roller to ensure all material flowed through the nip of the rollers under fairly uniform pressure. Material was forced through the rollers cyclically during each forward stroke of the ram.

The lower inner surface of the feed barrel was aligned with the surface of the lower roller and the position of the upper roller was adjusted to achieve the desired pressure. The flow between the rollers was usually initiated with minimal pressure being applied by the rollers. The upper roller was then lowered in increments.

A substantial sample of the discharged material was taken to determine moisture content once steady operating conditions had been achieved.

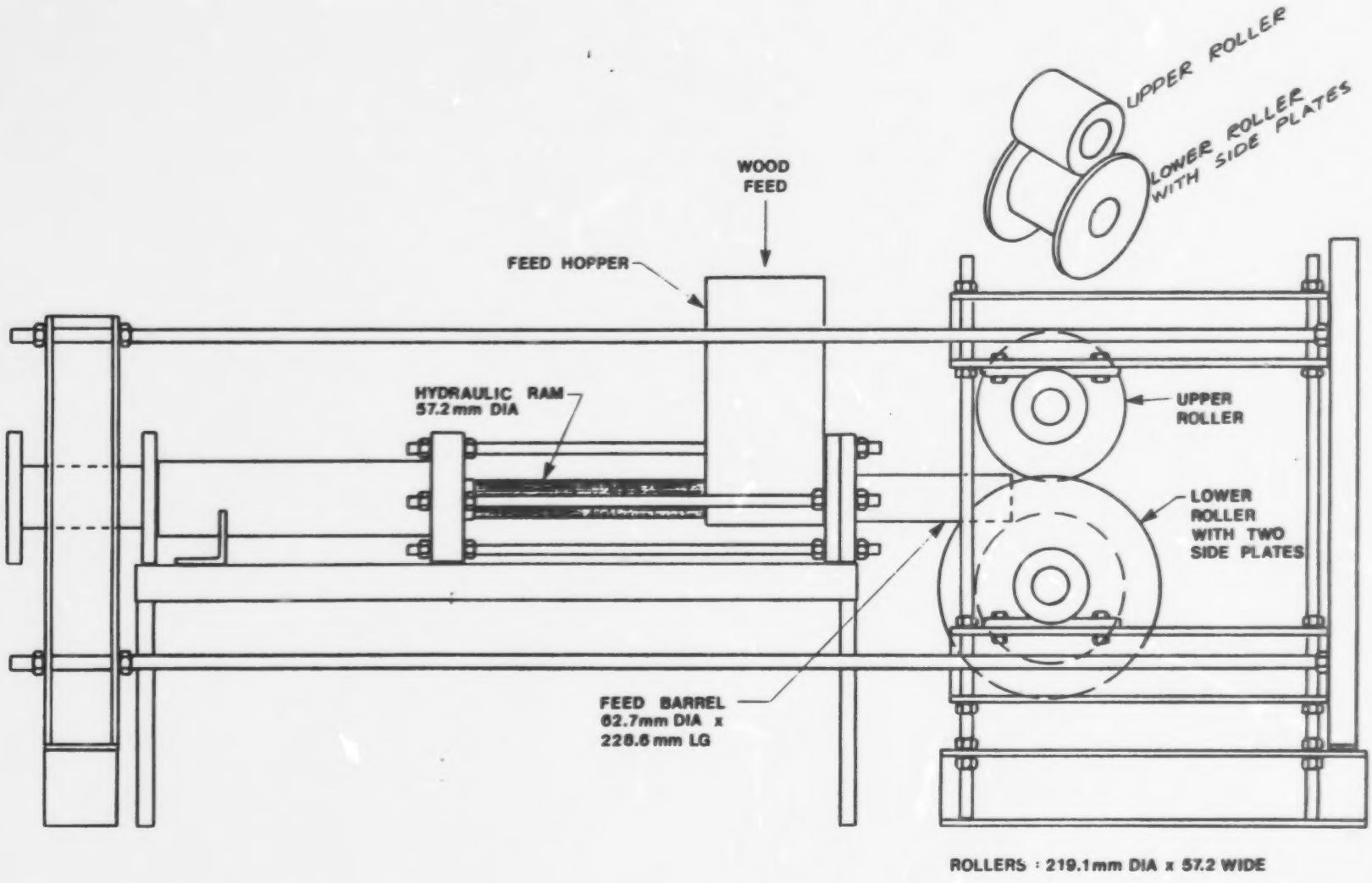

UPPER ROLLER
LOWER ROLLER WITH SIDE PLATES
WOOD FEED
FEED HOPPER
HYDRAULIC RAM 57.2mm DIA
UPPER ROLLER
LOWER ROLLER WITH TWO SIDE PLATES
FEED BARREL 62.7mm DIA x 228.6mm LG
ROLLERS : 219.1mm DIA x 57.2 WIDE

FIGURE V-4 ROLLER PRESS TEST UNIT

Some test runs were made using the dewatering section from the ram press located between the feed hopper and the feed barrel. In this case water was expressed at the dewatering section and at the rollers.

The pressure developed over the area between the rollers is the pressure used to present results of the tests. The pressure developed on the material between the rollers could not be measured directly, but was calculated by dividing the load applied at the face of the ram feeder by the area between the rollers.

The general procedures used for the tests with the roller press were:

- add material in small batches to the feed hopper;
- cycle the feed ram at the maximum rate for the pressure applied. The cycle time varied with peak pressure and other conditions from 20 - 50 seconds.
- continue feeding material until material is moving through the rollers and the ram pressure is consistent for each cycle;
- continue feeding and collect the discharged material for measuring its moisture content. Typically, 250 - 350 grams of product were collected and dried to measure moisture content.

B. Feed Materials

1. Source and Type

Dewatering tests were done with the three press units using Western hemlock chips and hog fuel obtained from Canadian Forest Products' Eburne Sawmill in Vancouver. The wood chips are normally sold by the mill for pulping. The hog fuel obtained for the tests was taken from the fuel stream going to the plants' boiler. The hog fuel at the plant consists of a mixture of wood residues from various mill operations and bark from the mechanical debarker that has been hogged.

2. Size Distribution

The size distribution of the hog fuel and chips used for all tests is shown in Figures V-5 and V-6, respectively. The average and range of the weight fractions passing each screen size are based on nine samples, in the case of wood chips, and ten samples, in the case of hog fuel. Since all feed materials were obtained during the course of the tests from the same mill processing the

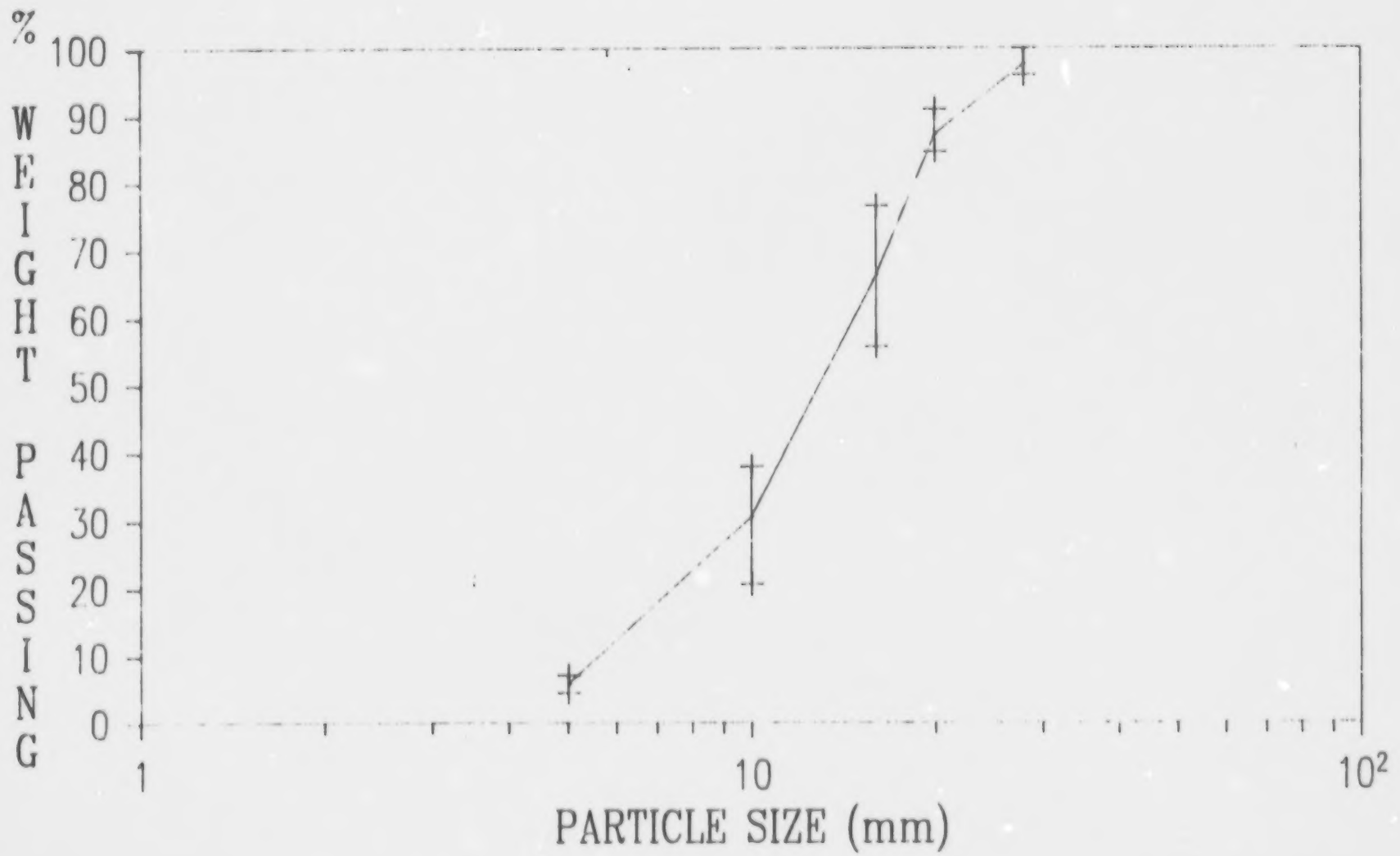


FIGURE V-5 PARTICLE SIZE DISTRIBUTION OF HEMLOCK WOOD CHIPS

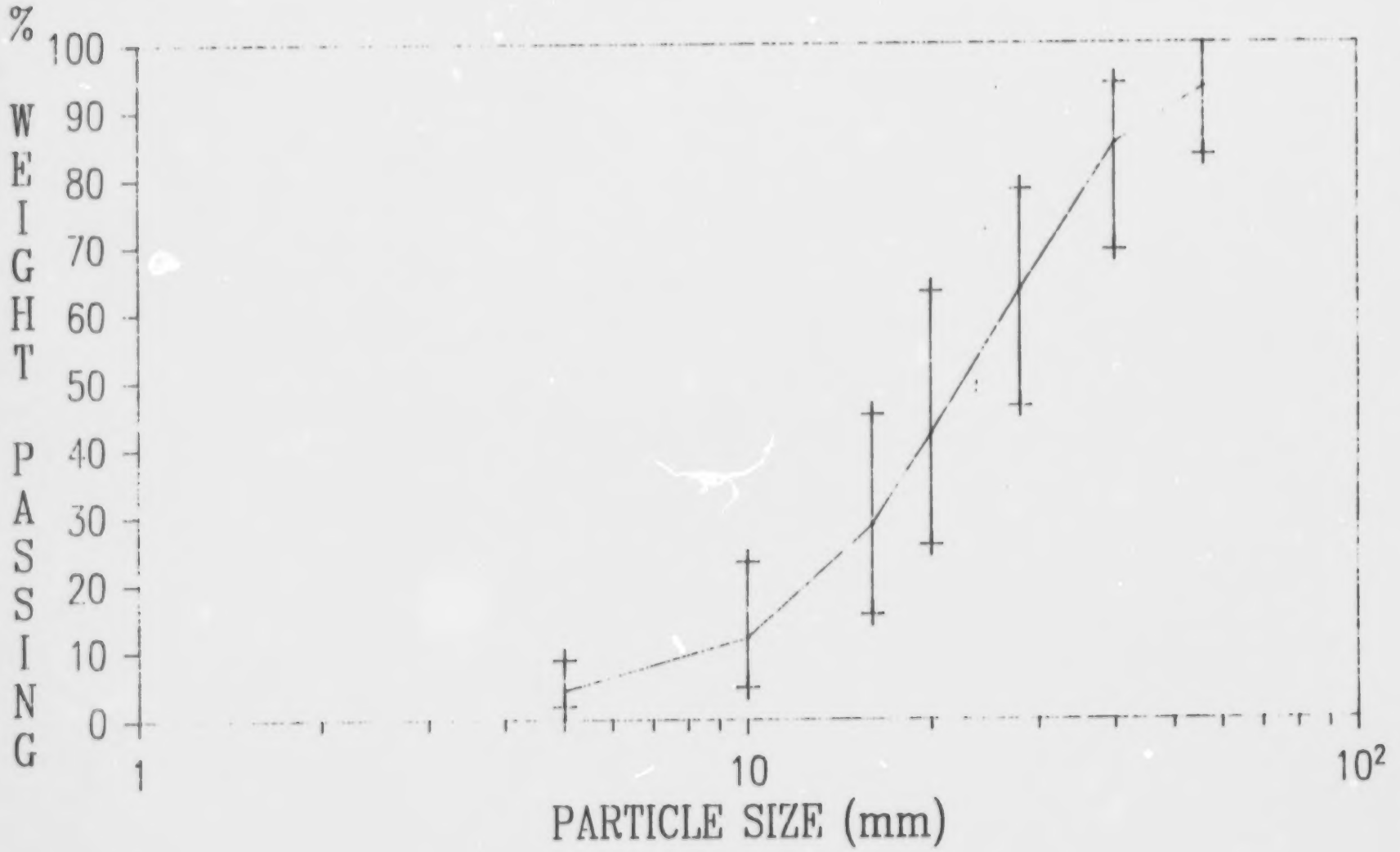


FIGURE V-6 PARTICLE SIZE DISTRIBUTION OF HEMLOCK HOG FUEL

same species, it is assumed that the size distribution remain within the measured ranges.

3. Bulk Density

The bulk density of both the wood chips and the hog fuel was measured using the 184.2 mm diameter (inside) test cell used with the platen press. The cell was filled to near the top and lightly packed using the dead weight of the ram. The bulk densities based on dry weight measured in this way were:

	Number of Samples	Bulk Density (OD kg/m^3)	Moisture Content (%, wb)
Wood chips	30	126.7	47.74
Hog fuel	30	178.2	48.07

4. Moisture Content

Tests were done with feed at an as-received moisture content, and after being soaked in water and allowed to drain. The as-received moisture contents were typically near 48% for both wood chips and hog fuel. To obtain material having a very high moisture content it was placed in a medium-sized container, immersed in water for 24 hours, then covered with a coarse screen, inverted and allowed to drain for four hours. The resulting material was then covered until used, usually the same day. This feed had a moisture content of 60% or more.

VI. TEST RESULTS

A. Platen Press

1. Mat Compression and Density

The mat height was recorded at the start and after the peak pressure had been reached for all test runs. These results were averaged for each pressure series to determine the effect of pressure on mat density and percent mat compression.

The change of bulk density and compression with pressure for wood chips is given in Figure VI-1. Mat density increased rapidly from an average initial value of 0.1267 ODg/cc to 0.686 ODg/cc at 9.97 MPa then increased gradually to 0.8377 ODg/cc at 25.07 MPa.

The data measured for compression, C, as a function of applied pressure was analyzed to develop a suitable correlation. All data was fit to an equation of the form:

$$C = \frac{AP^b}{100}$$

with P in MPa and C as a fraction. The coefficients determined for as-received and soaked chips and hog fuel are summarized in Table VI-1. As can be seen by the coefficients of determination, the data is fit well by the single-order polynomial used.

2. Effect of Pressure and Residence Time

The moisture content of the materials tested declined rapidly from its initial value in the early stage of compression. The incremental reduction in moisture content achieved by application of pressure decreasd as pressure increased, becoming relatively small at the peak pressure tested (25.07 MPa) as shown for chips and hog fuel in Figures VI-3 and VI-4, respectively.

Starting with chips having a moisture content of 46.3 - 49.7%, application of 25.07 MPa reduced the moisture content to 35.5 - 38.5%, depending on how long the material was held in the press at peak pressure. Pressing of material having a high moisture content (59.0 - 63.4%) at the maximum pressure tested (25.07 MPa) reduced the moisture content to 35.2 - 40.4%, depending on the time at pressure. The results show the effect of residence time is significant. This is shown more clearly for chips in Figure VI-5. The moisture content reduction achieved by holding the material at pressure for two minutes is generally greater than that achieved after one minute. Results were not consistemt for all runs, though in several runs the moisture

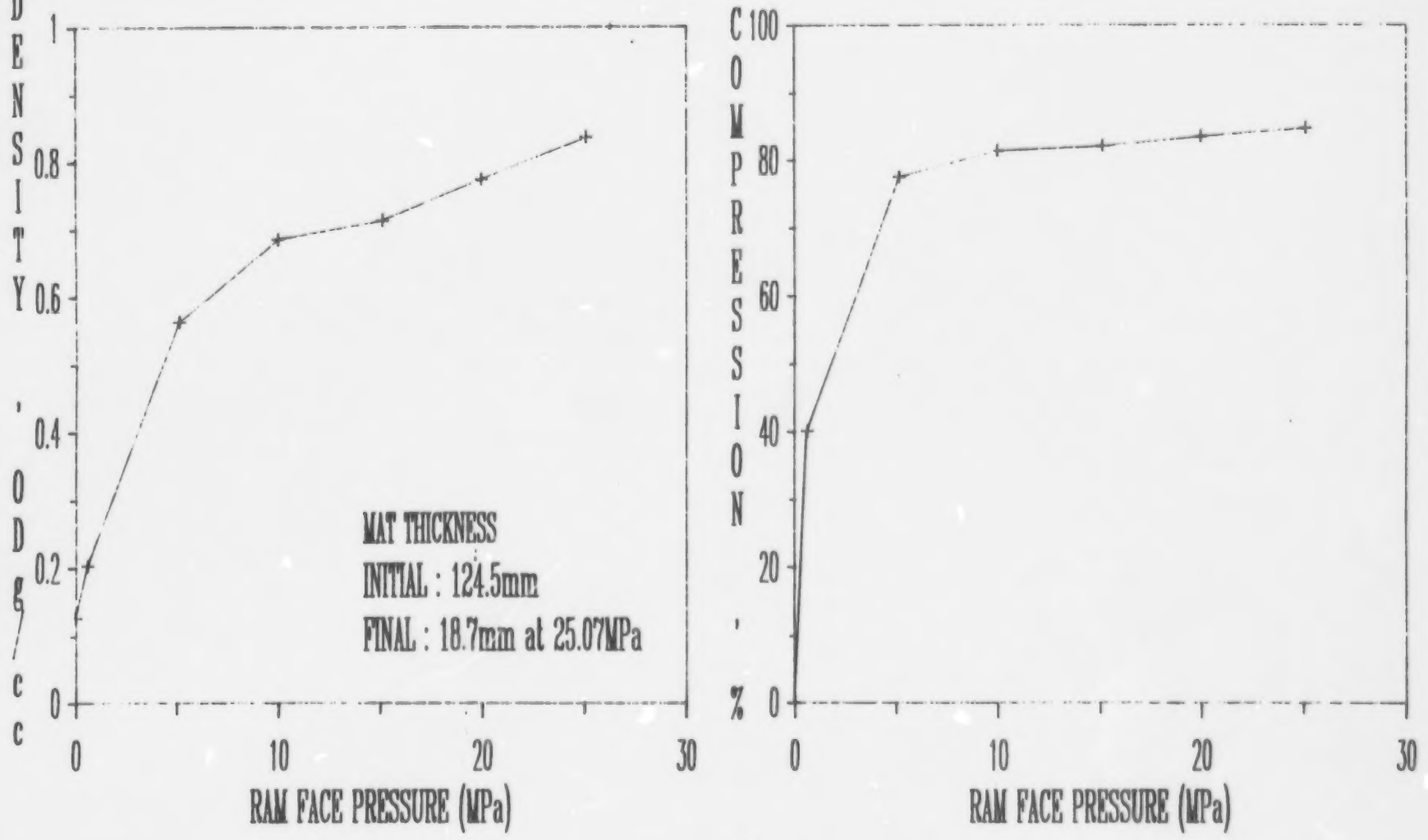


FIGURE VI-1 MAT DENSITY AND COMPRESSION OF HEMLOCK WOOD CHIPS UNDER VARIOUS PRESSURES

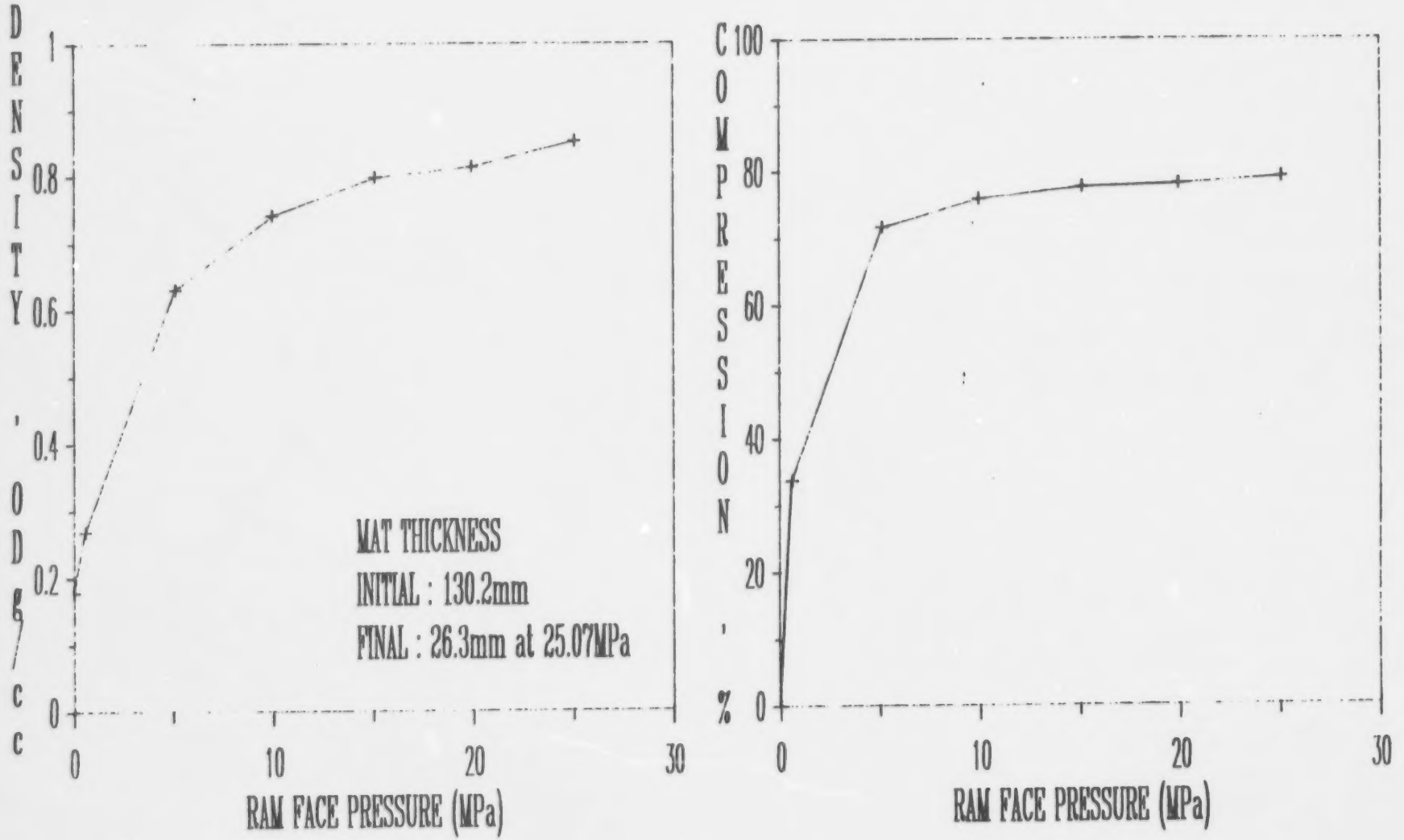


FIGURE VI-2 MAT DENSITY AND COMPRESSION OF HEMLOCK HOG FUEL UNDER VARIOUS PRESSURES

TABLE VI-1 COEFFICIENTS FOR RELATIONSHIP BETWEEN COMPRESSION AND PRESSURE IN A PLATEN PRESS

MATERIAL	AVERAGE INITIAL MOISTURE CONTENT (%, db)	EQUATION COEFFICIENTS[a] A	b	R^2
Chips, as-received	91.34	70.47	0.0578	0.9908
Chips, soaked	152.78	70.75	0.0569	0.9649
Hog fuel, as-received	96.54	66.70	0.0561	0.9675
Hog fuel, soaked	153.22	65.20	0.0605	0.9900

[a] Coefficients for the equation for volumetric compression, C

$$C = \frac{AP^b}{100}$$

where C = (Initial volume - Final Volume)/Initial Volume

P = applied pressure (MPa)

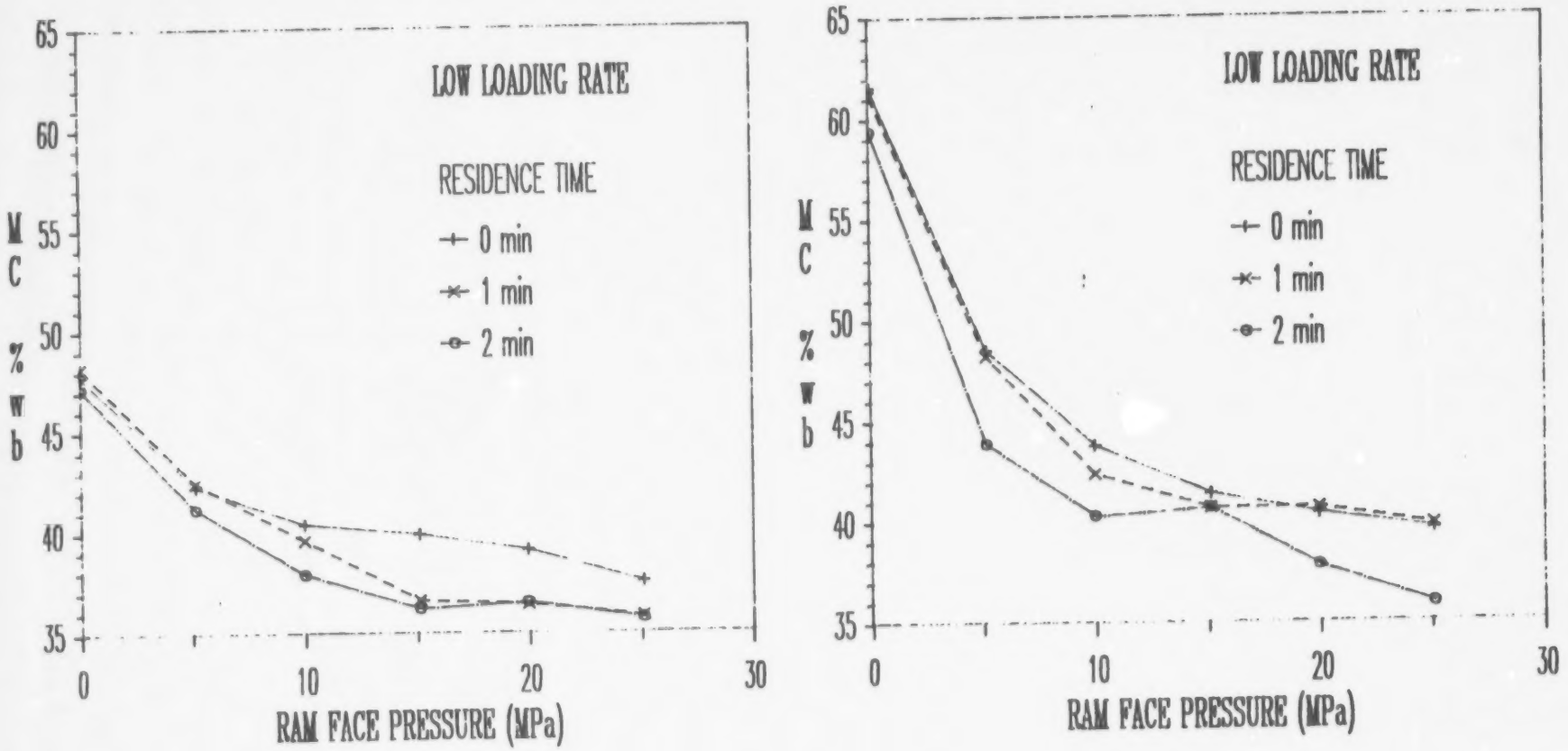


FIGURE VI-3 EFFECT OF PRESSURE ON THE MOISTURE CONTENT OF HEMLOCK WOOD CHIPS

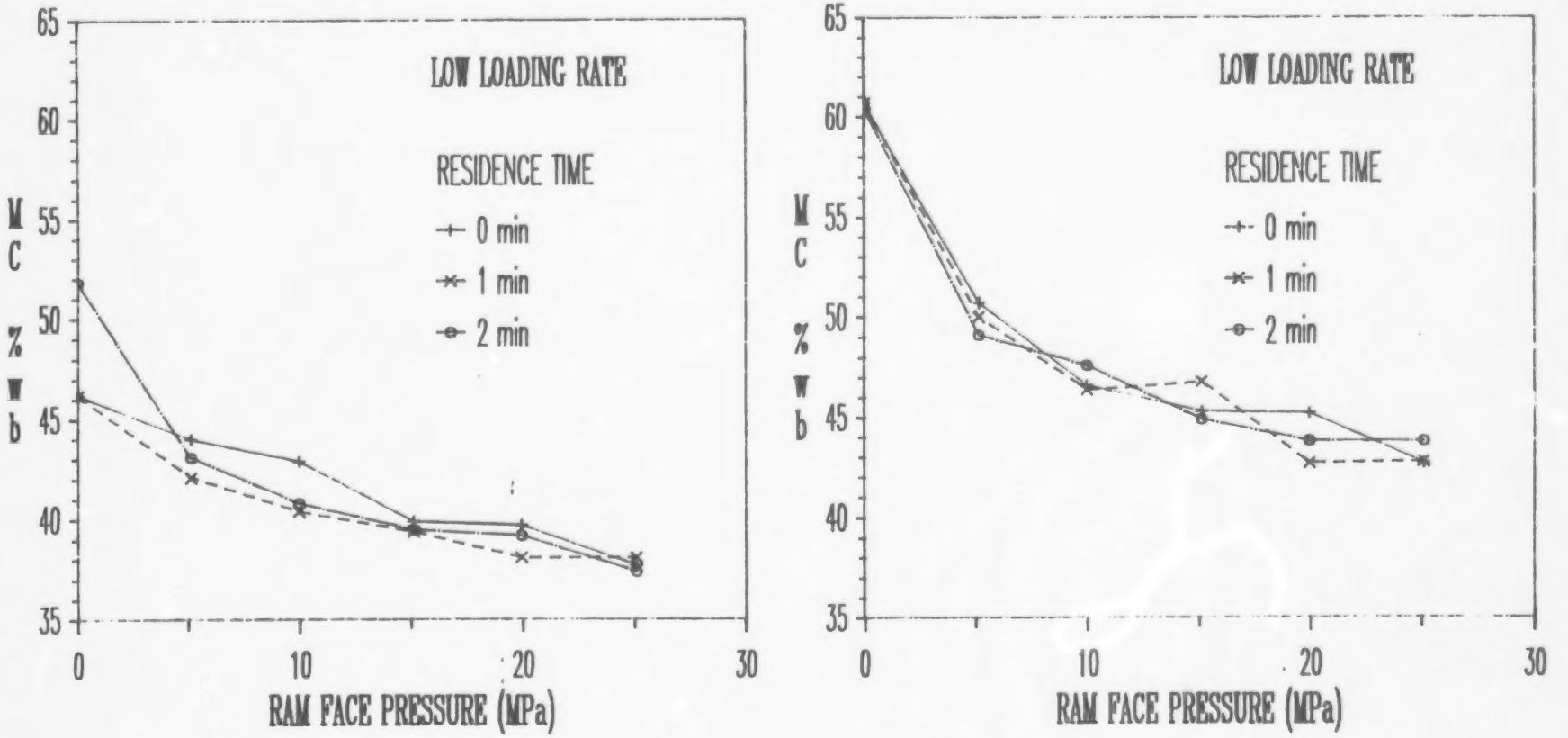


FIGURE VI-4 EFFECT OF PRESSURE ON THE MOISTURE CONTENT OF HEMLOCK HOG FUEL

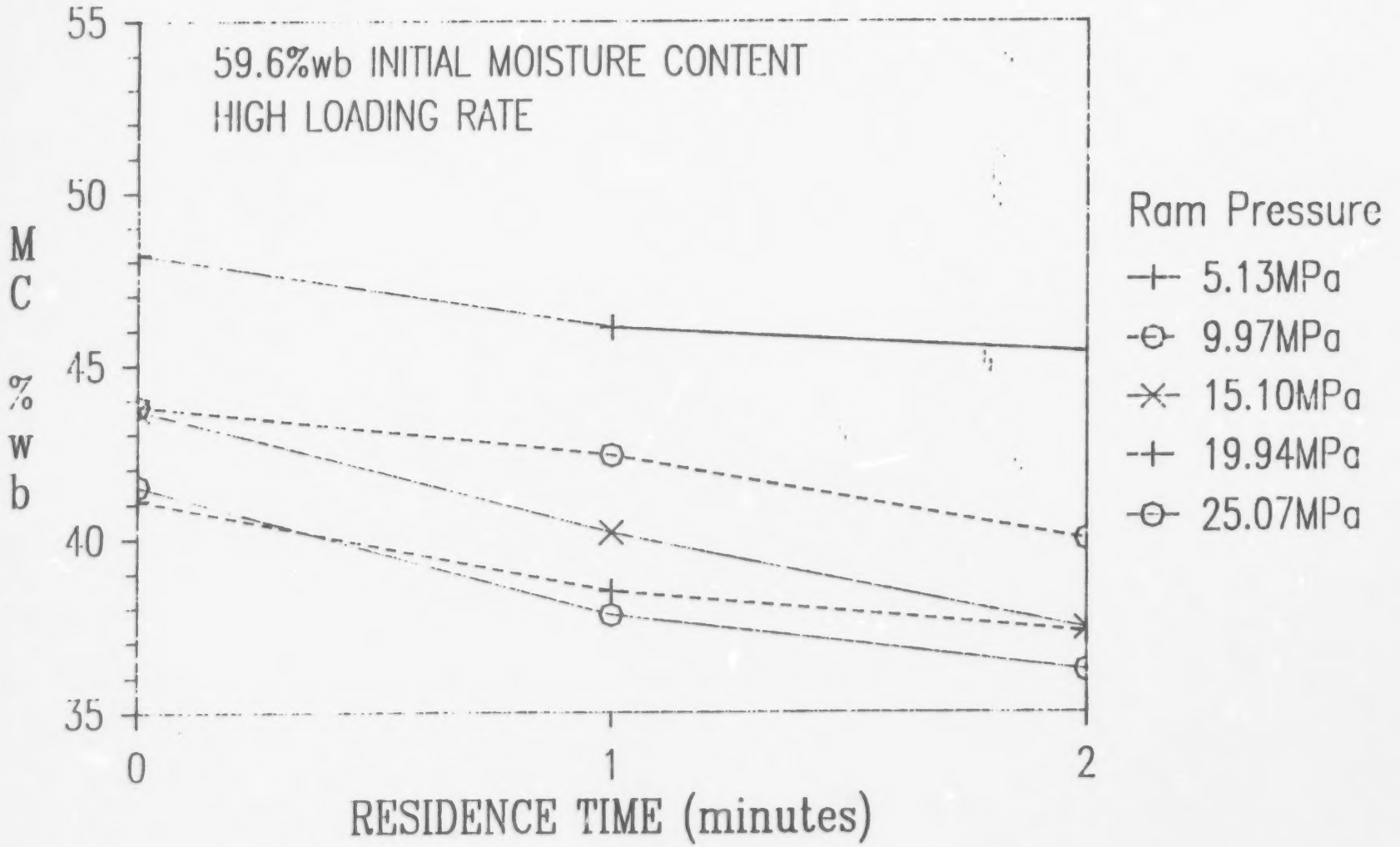


FIGURE VI-5 EFFECT OF RESIDENCE TIME ON THE MOISTURE CONTENT OF HEMLOCK WOOD CHIPS

content reduction achieved decreased as the residence time increased. This behavior was also observed by Haygreen and Steklenski (1985), who found that use of pressing times greater than 3 minutes resulted in very little additional reduction of the moisture content.

Tests with hog fuel indicated that moisture content could be reduced from an initial value of 45.9 - 51.8% to a value of 37.6 - 38.3% by application of 25.07 MPa (Figure VI-4). The additional drying achieved by increasing pressure becomes very small at or above the maximum pressure tested. When starting with feed soaked in water having a moisture content of 60.4 - 61%, the moisture content could be reduced to 41.5 - 44% at a pressure of 25.07 MPa. The minimum moisture content achieved for the soaked feedstock was significantly higher than what was found for the as-received feedstock, indicating a dependency on initial moisture content exists.

As for chips, the moisture content achieved at the pressures tested varied with residence time. The effect of residence time was more variable for hog fuel than for wood chips, with in some cases longer times being counterproductive, while in others it being productive (Figure VI-6). These inconsistencies are probably caused by subtle differences in the feedstock and experimental conditions.

3. Effect of Initial Moisture Content

The moisture content achieved by pressing was dependent on the initial moisture content, being higher when wetter feed was used. The effect of initial moisture content is shown for chips in Figure VI-7 for residence times of 0 and 2 minutes. Results from the test using a 2 minute residence time suggest that the effect of initial moisture content is not decreased or eliminated by pressing the material for a longer period. A greater affect of initial moisture content was observed for hog fuel (Figure VI-8). As for the chips, holding the material at pressure for up to 2 minutes does not negate the affect of initial moisture content.

4. Effect of Loading Rate

The effect of the rate of application of pressure in the moisture content was investigated over the limited range possible with the press. The pressing rate could only be changed below a ram face pressure of 4.7 MPa, which, for the higher pressures tested, was a relatively small portion of the pressing process. The average time to peak pressure has been tabulated previously (Table V-1) for both chips and hog fuel. The difference between the high and low loading rates was relatively small as illustrated by times to reach the lowest and highest pressures tested:

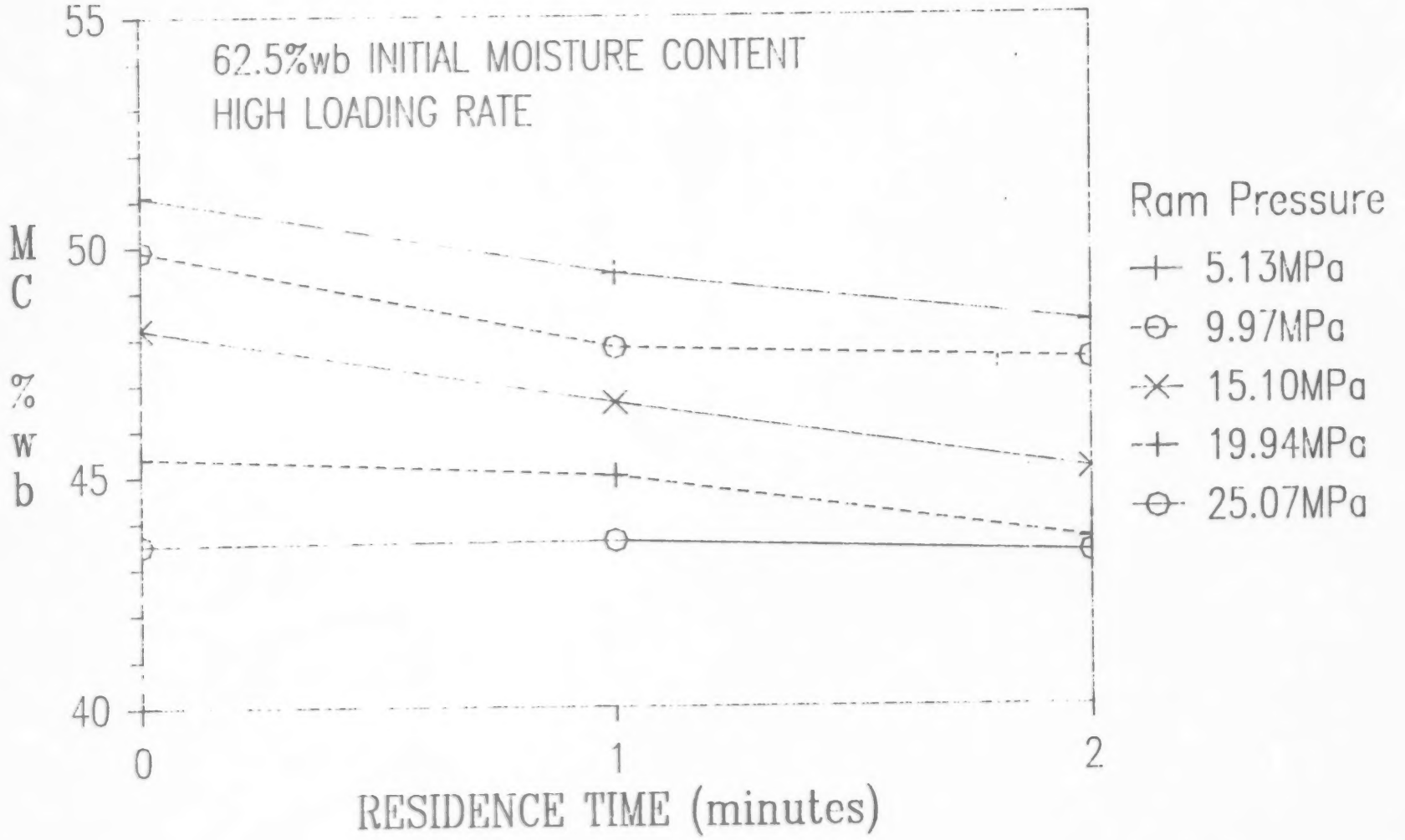


FIGURE VI-6 EFFECT OF RESIDENCE TIME ON THE MOISTURE CONTENT OF HEMLOCK HOG FUEL

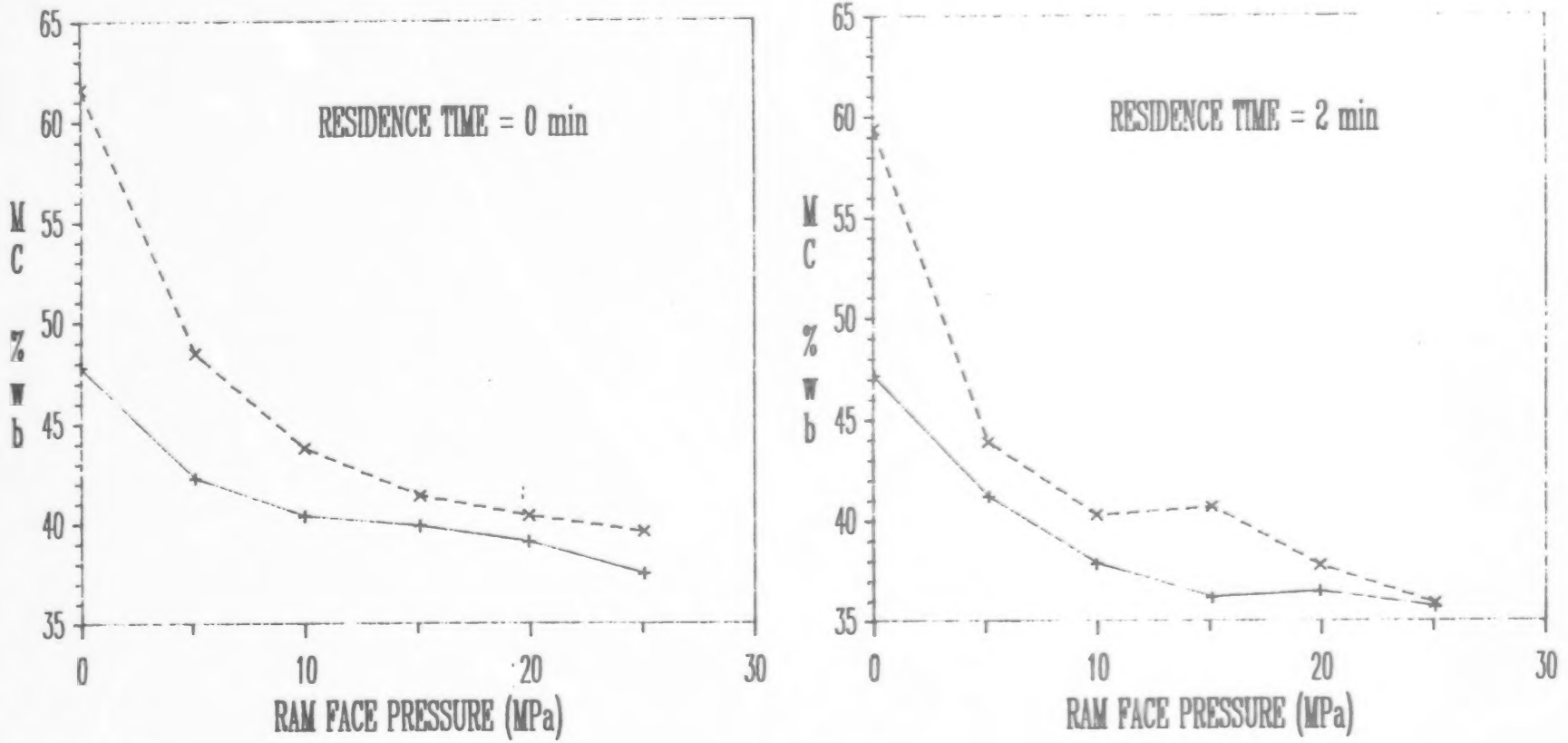


FIGURE VI-7 EFFECT OF INITIAL MOISTURE CONTENT ON THE FINAL MOISTURE CONTENT OF HEMLOCK WOOD CHIPS

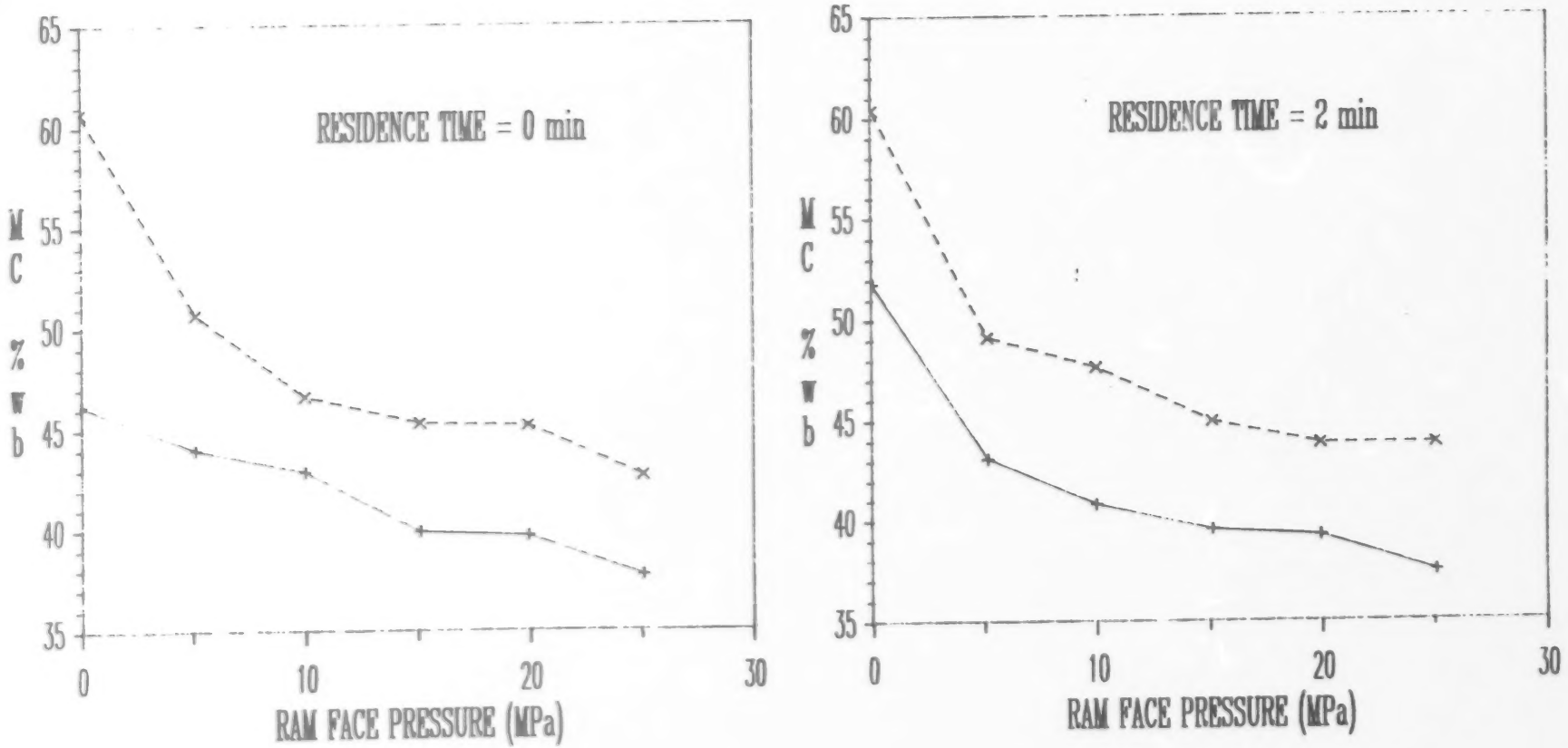


FIGURE VI-8 EFFECT OF INITIAL MOISTURE CONTENT ON THE FINAL MOISTURE CONTENT OF HEMLOCK HOG FUEL

Time to Pressure (seconds)

Pressure (MPa)	Chips		Hog Fuel	
	Low Rate	High Rate	Low Rate	High Rate
5.13	31.5	28.6	21.7	18.4
25.07	48.5	45.1	36.7	32.8

Test results for chips (Figure VI-9) do not show any consistent effects of loading rate over the range tested. Differences between results for the two loading rates are attributed to differences in the material and experimental error.

The moisture content results for hog fuel when a 2 minute residence time are essentially identical (Figure VI-10). The difference between the results for the two loading rate cases with a zero residence time are believed due to other factors.

5. Effect of Type of Feed

Tests were done with chips and hog fuel that are typical of what are used in the forest products industry. The feed materials were not screened or otherwise treated to modify their size distribution. One set of tests was done at the as-received moisture content, while the other set was done after soaking the feed in water.

Tests done with a residence time of 2 minutes and at a low loading rate were used to investigate the affect of fuel type (chips versus hog fuel) on moisture content (Figure VI-11). Data shown for chips and hog fuel at the as-received initial moisture content are similar. Unfortunately the as-received moisture contents of these two types of material were different, making a direct comparison of the results difficult. However, data for hog fuel from Figure VI-4 (given previously) indicate that similar moisture content results are achieved above a pressure of 5 MPa for initial moisture contents between 46% and 52%. With this information, the data given in Figure VI-11 for the low range of moisture content tested indicates chips dewater more readily than hog fuel. This is borne out by the results shown for tests done at a higher moisture content. The spread between the results for chips and hog fuel increases the higher the initial moisture content used.

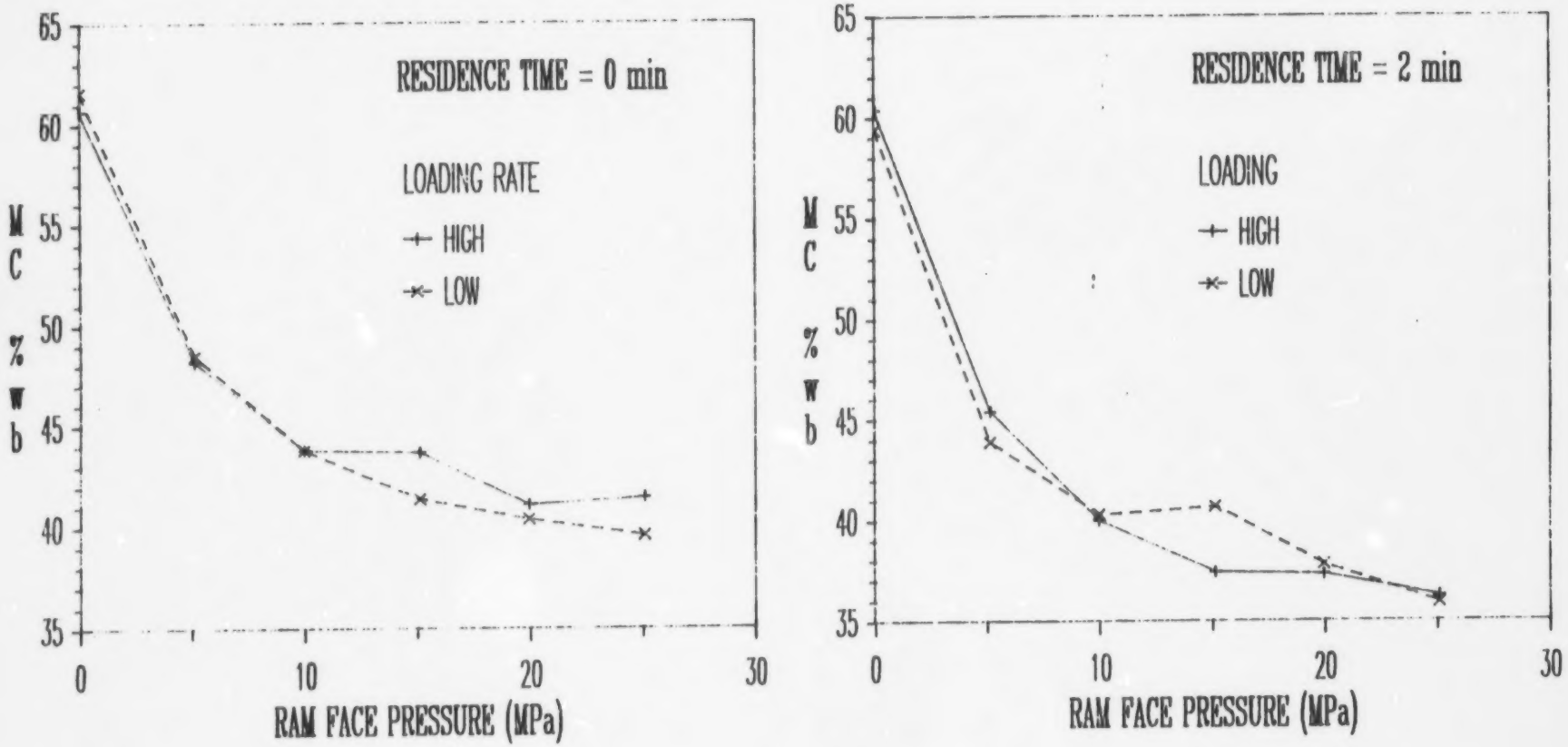


FIGURE VI-9 EFFECT OF LOADING RATE ON THE MOISTURE CONTENT OF HEMLOCK WOOD CHIPS

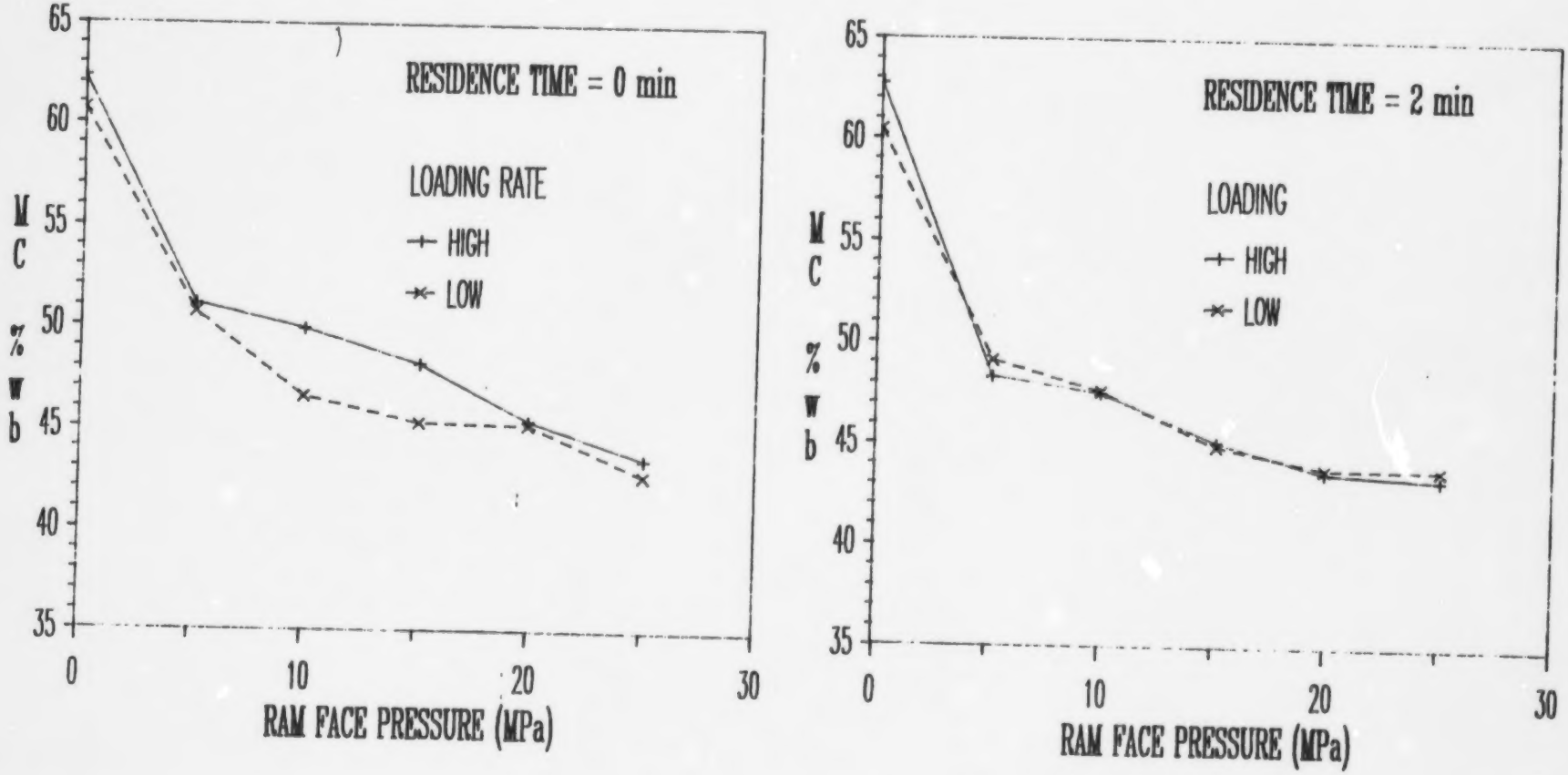
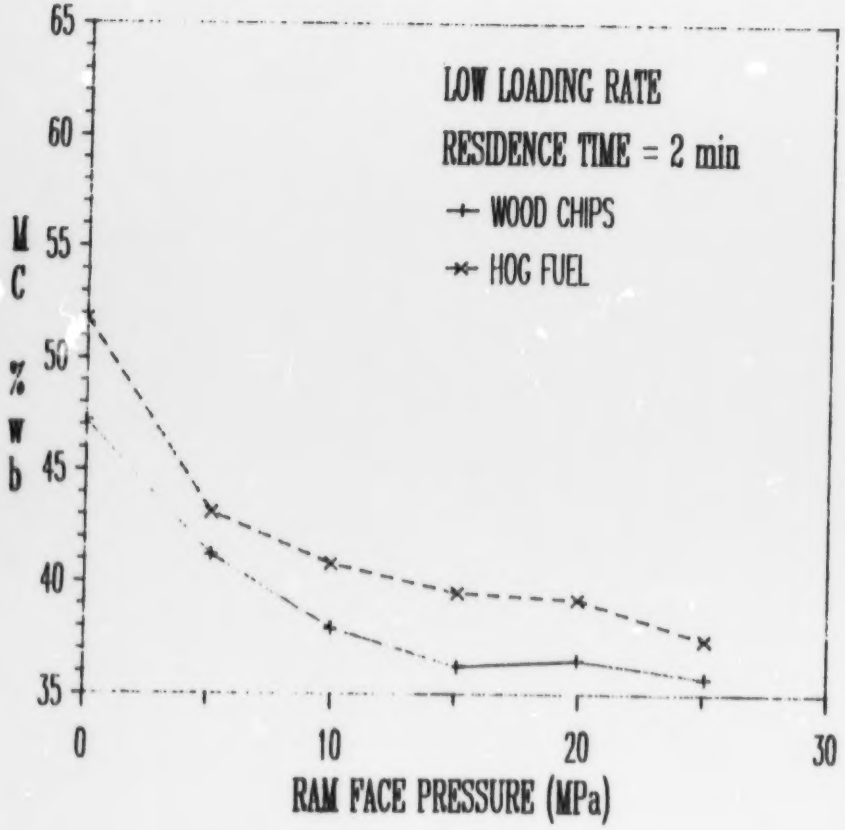


FIGURE VI-10 EFFECT OF LOADING RATE ON THE MOISTURE CONTENT OF HEMLOCK HOG FUEL



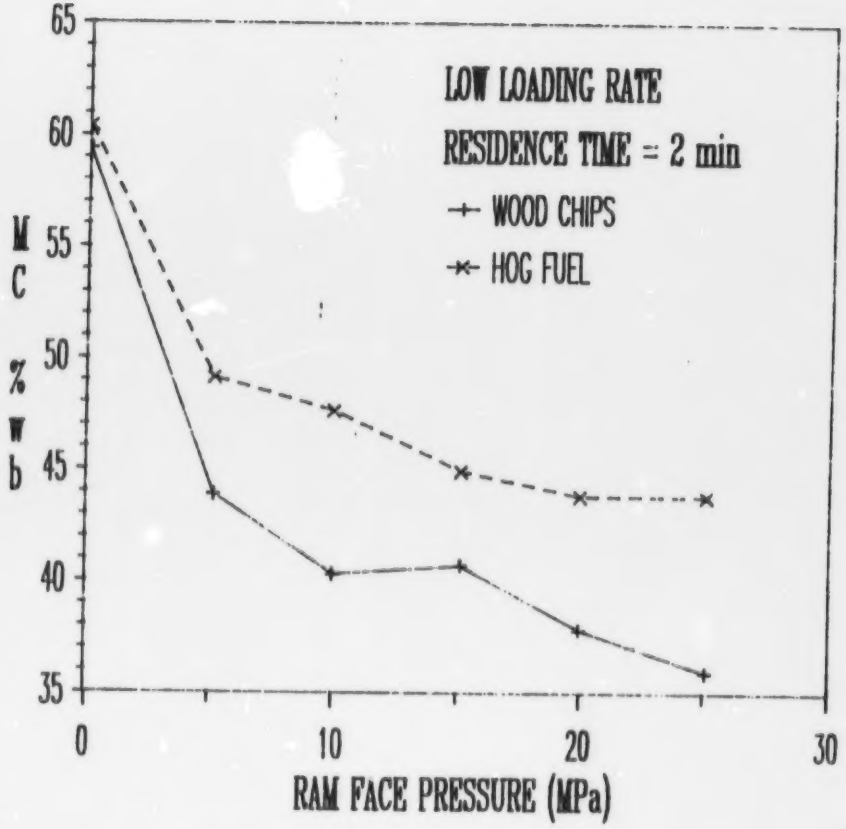


FIGURE VI-11 COMPARISON OF THE PRODUCT MOISTURE CONTENT FOR HEMLOCK WOOD CHIPS AND HOG FUEL FOR THE PLATEN PRESS

B. Ram Press

1. Effect of Pressure

Series of tests were done with chip and hog fuel feed materials using pressure over the range possible with the test press. To operate at different pressures, changes were made to the set up of the press to operate with different amounts of material in the barrel of the press. These changes were accomplished by using different ram strokes (101.6 mm and 203.2 mm), and barrels of different lengths (152.4 mm, 228.60 mm and 304.8 mm). By combining stroke lengths and alternate barrel attachments, tests could be done at pressures spread fairly uniformly through the equipment's range.

Most tests were done with a solid end barrel. In this arrangement, all water removed mechanically was expressed through the dewatering section attached at the start of the barrel. When operating with a 102 mm stroke, the ram travelled to the midpoint of the dewatering section. Use of the 203 mm stroke caused the ram to travel completely through the dewatering section to the flange where alternate barrel ends were attached. Some tests were done with a 228.6 mm long barrel perforated for 177.8 mm of its length with eight sets of 3.175 mm holes spaced at 12.7 mm intervals. The eight holes in each set were equally spaced around the perimeter of the barrel.

The ram face pressure was not steady as pressure was applied to material in the dewatering section, but oscillated as illustrated in Figures VI-12 and VI-13. The oscillation of pressure was caused by a stick-slip phenomenon in which pressure increases as the material remains static in the barrel until a critical pressure is reached, then the material begins to slide and the pressure drops rapidly. When the material once again comes to rest in the barrel, the stick-slip cycle is repeated. When operating at low to moderate pressure, the ram goes through several stick-slip events until the end of the stroke is reached (Figure VI-12). The peak pressure for each stick-slip event decreases as the ram advances and the length of material in the barrel decreases. At high pressure, two or three stick-slip events occur, with associated large fluctuations in pressure. Stick-slip of the material occurred with chips in the as-received or the soaked condition, indicating that the presence of additional water in the material does not moderate or eliminate the stick-slip problem.

Figure VI-14 shows the stick-slip problem is common to hog fuel as well as chips. Similar behavior was also observed for sawdust tested in a limited number of runs. The pressure required

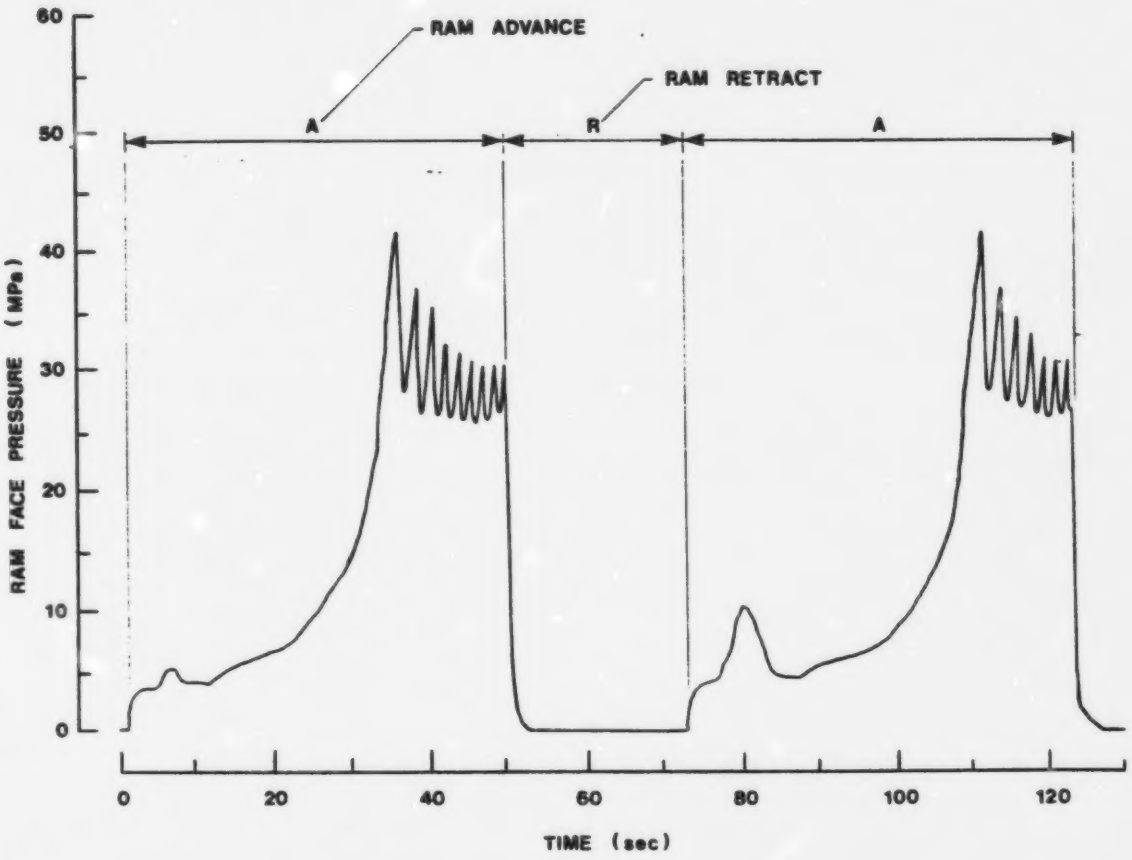


FIGURE VI-12 RAM FACE PRESSURE DURING PRESS CYCLE FOR WOOD CHIPS (MODERATE PRESSURE)

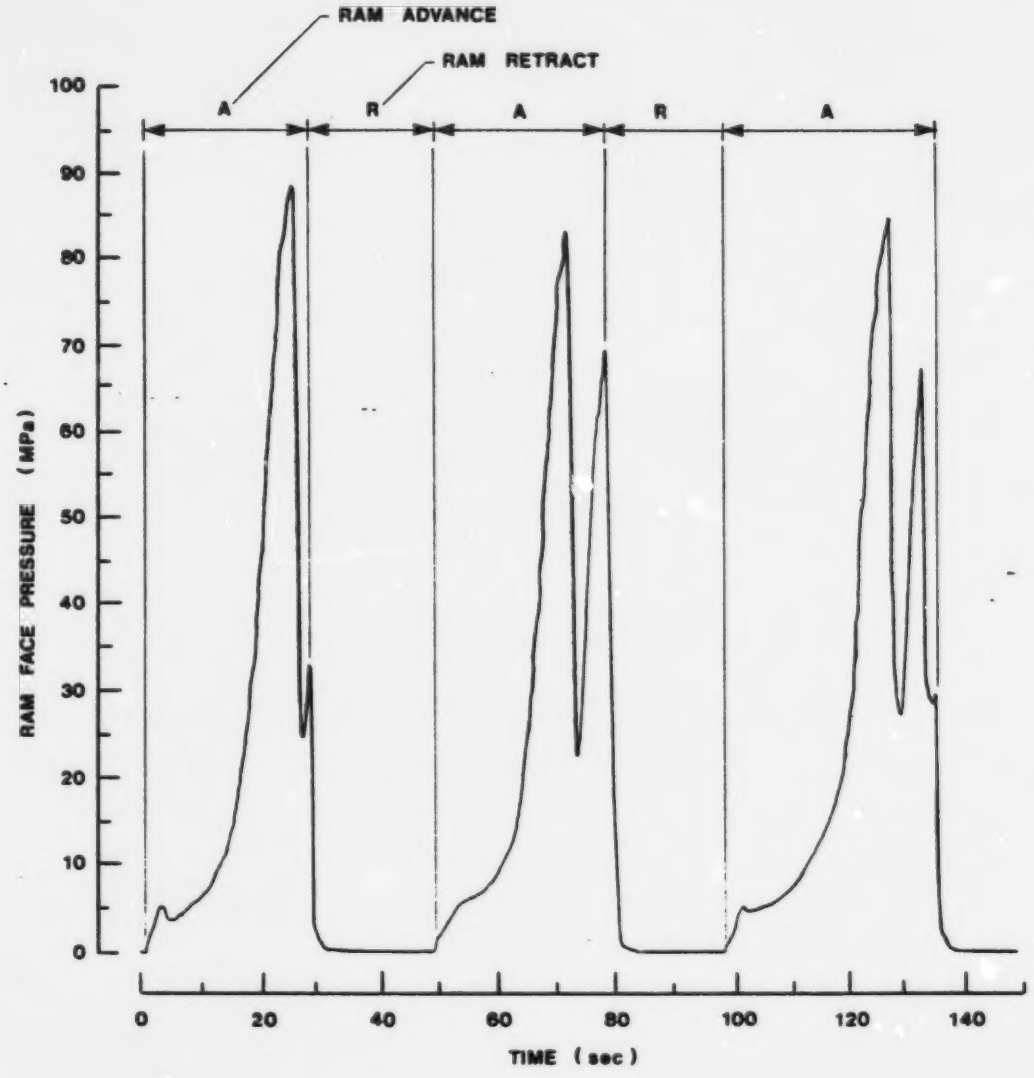


FIGURE VI-13 RAM FACE PRESSURE DURING PRESS CYCLE FOR WOOD CHIPS (HIGH PRESSURE)

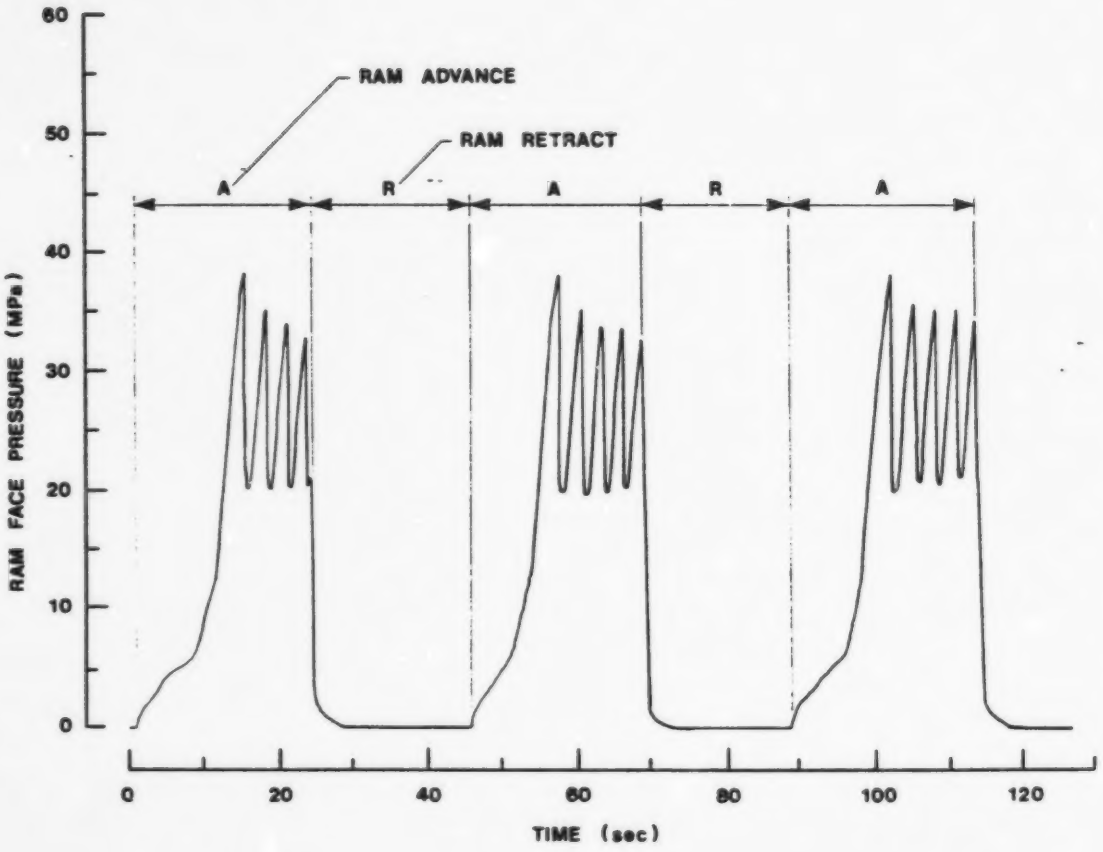


FIGURE VI-14 RAM FACE PRESSURE DURING PRESS CYCLE FOR HOG FUEL (HIGH PRESSURE)

to move hog fuel through the ram press was typically 30 - 50% of what was needed for wood chips.

The moisture content of wood chips declined with pressure as shown in Figure VI-15 for both as-received and soaked feed material. The ram face pressure used to present this and other data for the ram press is the average of the maximum pressures reached during the sequence of press cycles used to produce a sample. The maximum pressure referred to here is the peak value during an advance of the ram, which normally occurred before the first stick-slip event.

Additional dewatering occurred with the use of a perforated die, resulting in lower product moisture content (Figure VI-15). The benefit of using additional dewatering area is insignificant at the peak pressure used during the tests, but becomes more significant at lower pressures.

For both as-received and soaked feed materials, significant reduction of the product moisture content continues up to a pressure of 50 - 60 MPa.

The decline in moisture content with increasing pressure was more erratic for hog fuel than that found for chips Figure VI-16). The tests with hog fuel were done at pressures up to about 38 MPa, with the non-perforated die, and about 50 MPa with the perforated die. The pressure range investigated for hog fuel was lower than what was used for wood chips because of the inherently lower back pressure developed by the material in the barrel. Unlike wood chips, little dewatering occurred for the as-received feed up to 5 MPa pressure. The use of additional dewatering area led to a slightly lower product moisture content for both the as-received and soaked feed material.

2. Effect of Initial Moisture Content

Data for wood chips and hog fuel are shown in Figures VI-17 and VI-18, respectively, to illustrate the affect of initial moisture content. In the case of wood chips, the additional water present in material having a high moisture content is removed at low pressure (<7 MPa), resulting in essentially the same decline of moisture content with pressure above 10 MPa for the two feed cases considered.

Similar behavior was observed for hog fuel. The moisture content of the hog fuel samples which started at an as-received value were lower above 15 MPa pressure than those for samples starting in a soaked condition. Given the similarity of the moisture contents up to that pressure their subsequent divergence is surprising and attributed to experimental error. The relative

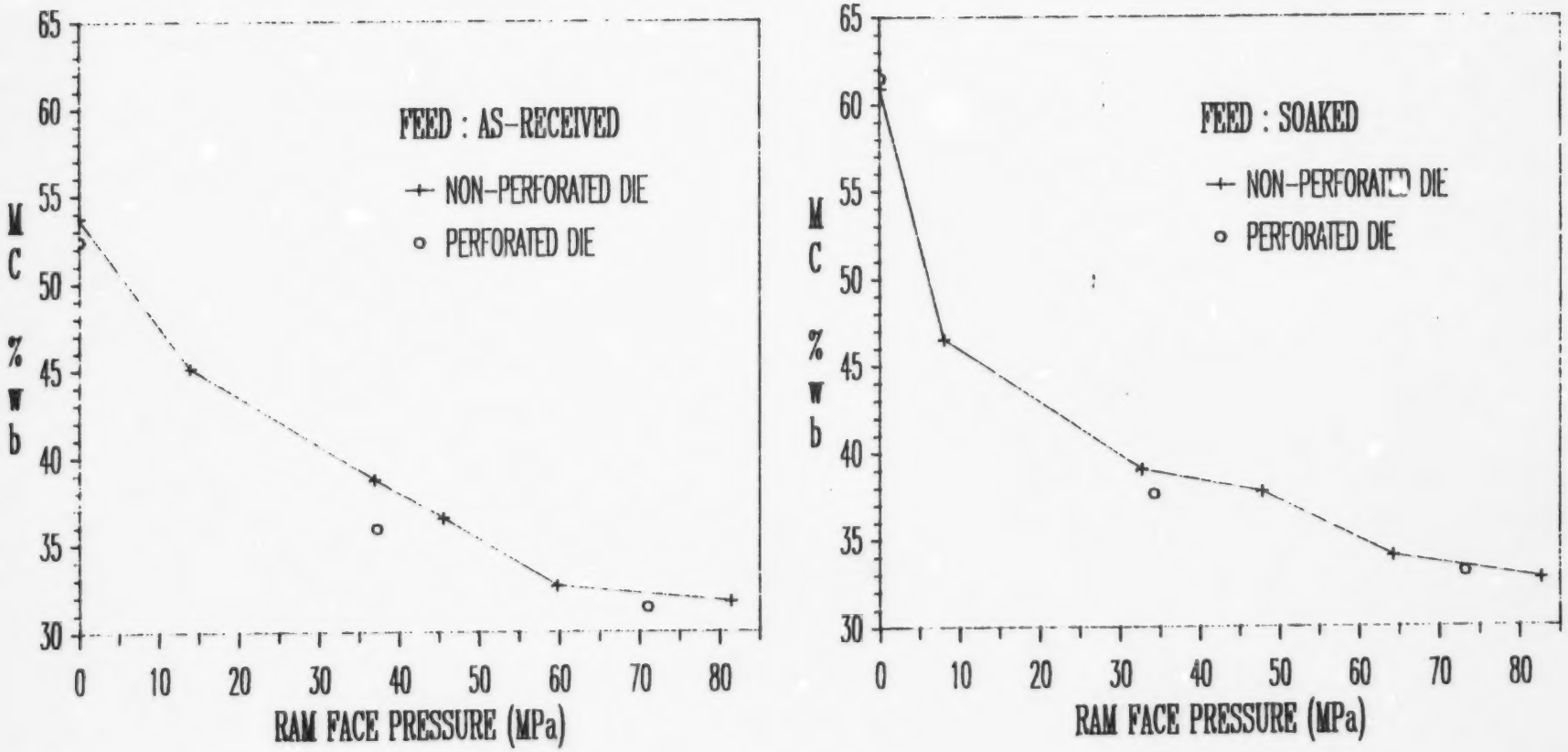
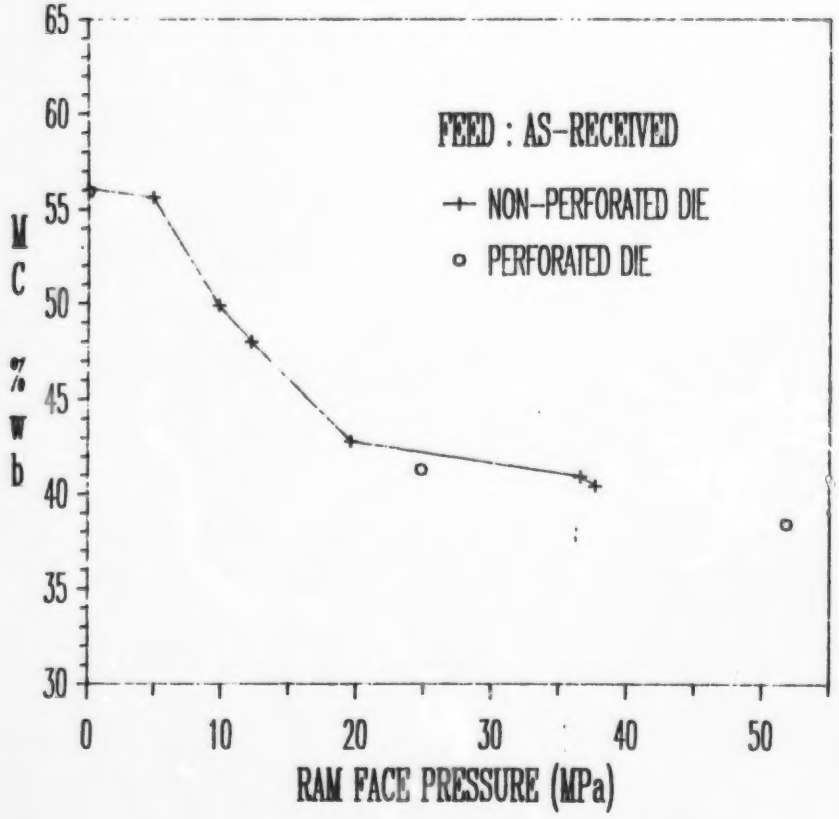


FIGURE VI-15 MOISTURE CONTENT OF HEMLOCK WOOD CHIPS FOR THE RAM PRESS



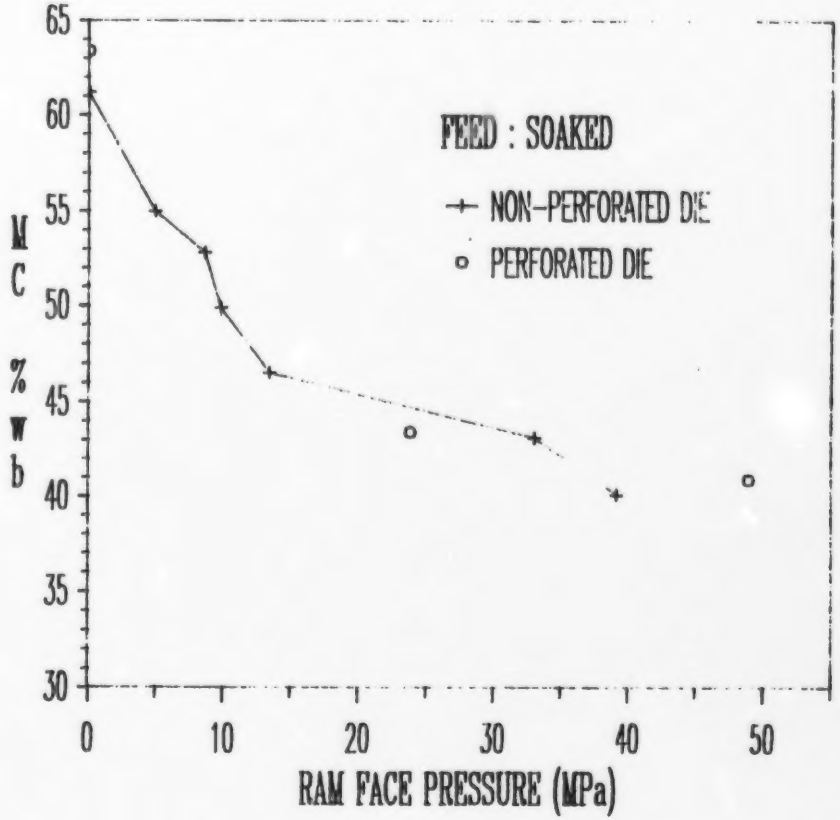


FIGURE VI-16 MOISTURE CONTENT OF HEMLOCK HOG FUEL FOR THE RAM PRESS

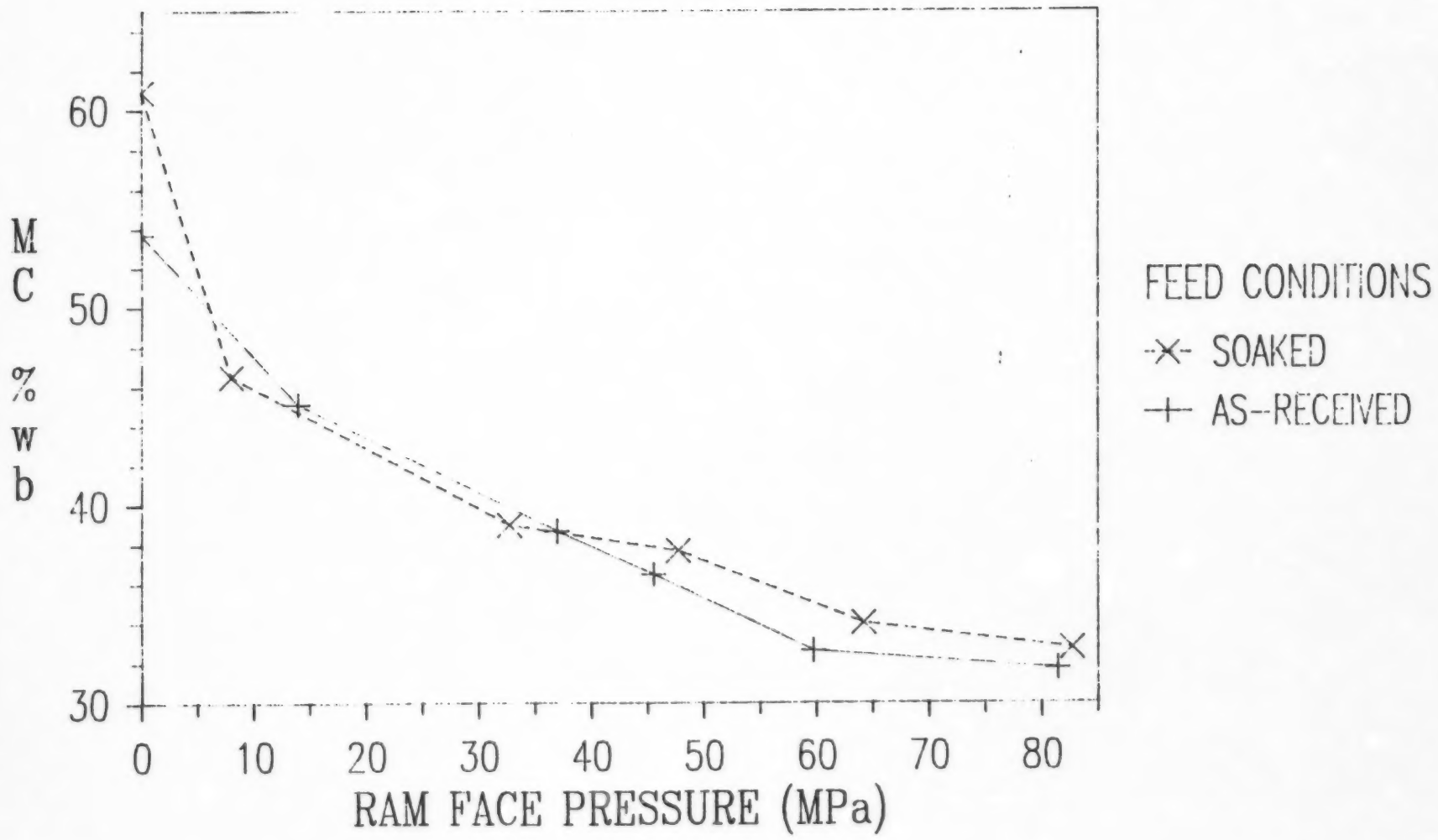


FIGURE VI-17 EFFECT OF INITIAL MOISTURE CONTENT ON THE FINAL MOISTURE CONTENT OF HEMLOCK WOOD CHIPS USING THE RAM PRESS

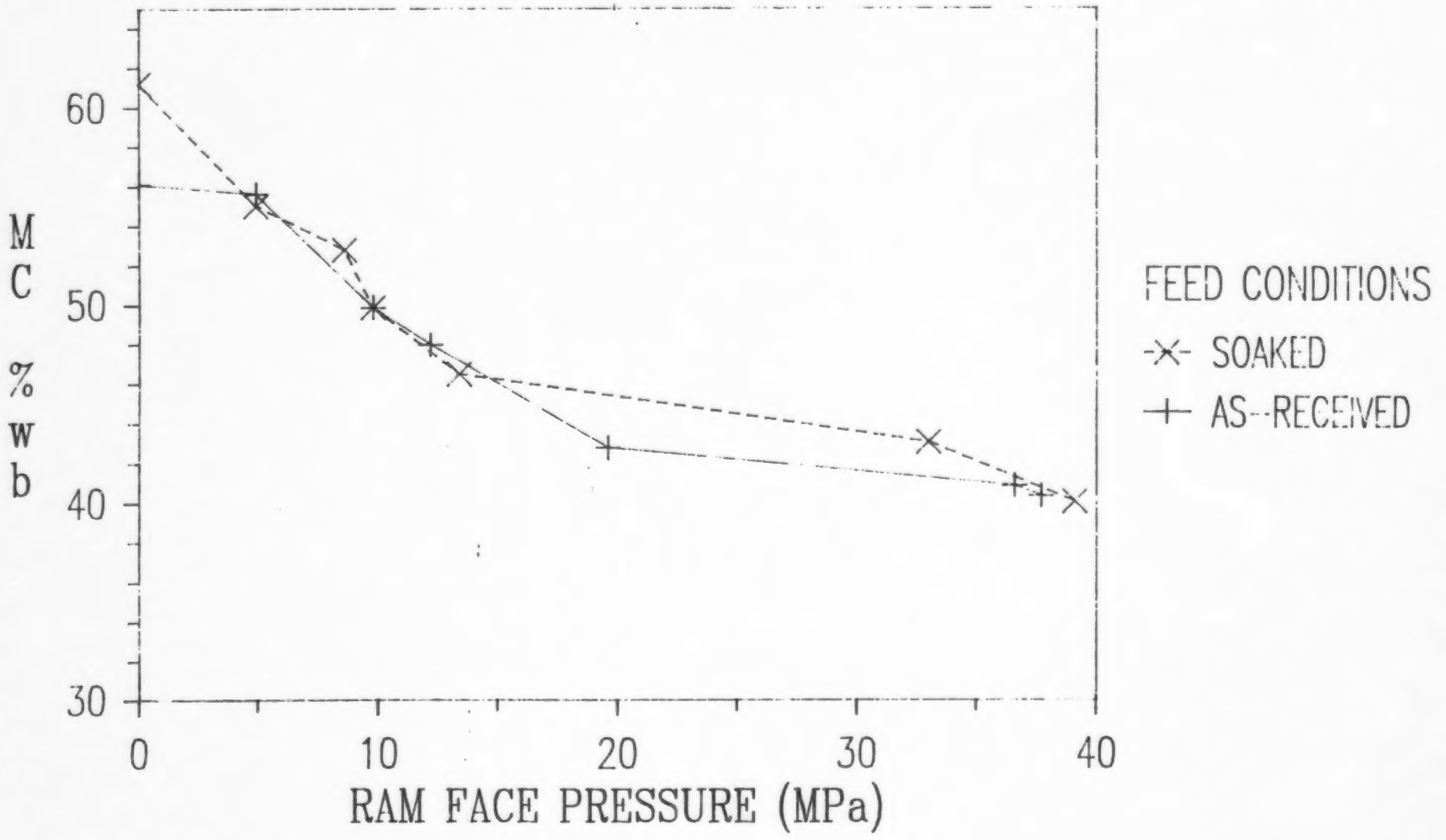


FIGURE VI-18 EFFECT OF INITIAL MOISTURE CONTENT ON THE FINAL MOISTURE CONTENT OF HEMLOCK HOG FUEL USING THE RAM PRESS

independence of product moisture content to the feed moisture content observed for wood chips and hog fuel is consistent with the performance of commercial bark presses. Haygreen and Steklenski (1985) observed a mild dependence of product moisture content on feed moisture content and concluded that the final moisture content of wood chips is 2 - 5% higher for each 10% increase in initial moisture content. Using this generalization over the same pressure range they tested (<27.6 MPa) one would expect an increase in product moisture content of 1 - 2.5% for hog fuel. Such a small difference would not be evident in the tests conducted.

3. Effect of Type of Feed

From a comparison of results for chips and hog fuel, it appears that hog fuel is more difficult to dewater. The product moisture content for chips and hog fuel in Figure VI-19 show that the difference in behavior between the two materials is consistent for soaked feed but inconsistent for as-received feed. Ignoring the one data point for as-received hog fuel at decline of moisture content with increasing pressure parallels that for wood chips, suggesting there is little difference in the dewatering characteristics of chips and hog fuel when starting from an as-received moisture content. However, as pointed out above, the dewatering of soaked hog fuel lags dewatering of soaked chips, all other test conditions being comparable.

C. Roller Press

1. Effect of Pressure

Tests were done with the roller press using two different configurations for water removal: with non-perforated barrel; and with partly perforated barrel. Tests with a non-perforated barrel were done using a 228.6 mm long non-perforated barrel feeding directly into the nip between the rollers. For runs with the partly perforated barrel, the 187.3 mm long dewatering section used for tests of the ram press was inserted at the start of the barrel, immediately following the feed hopper. With this arrangement, water was removed from the material in the dewatering section and at the rollers. Results for product moisture content from tests with the dewatering section in place should be similar to, or somewhat lower than, those for the ram press.

The effective pressure on the material for dewatering was calculated in the same way for the two configurations used for the tests. In all cases pressure was based on the cross-sectional area of the area between the rollers.

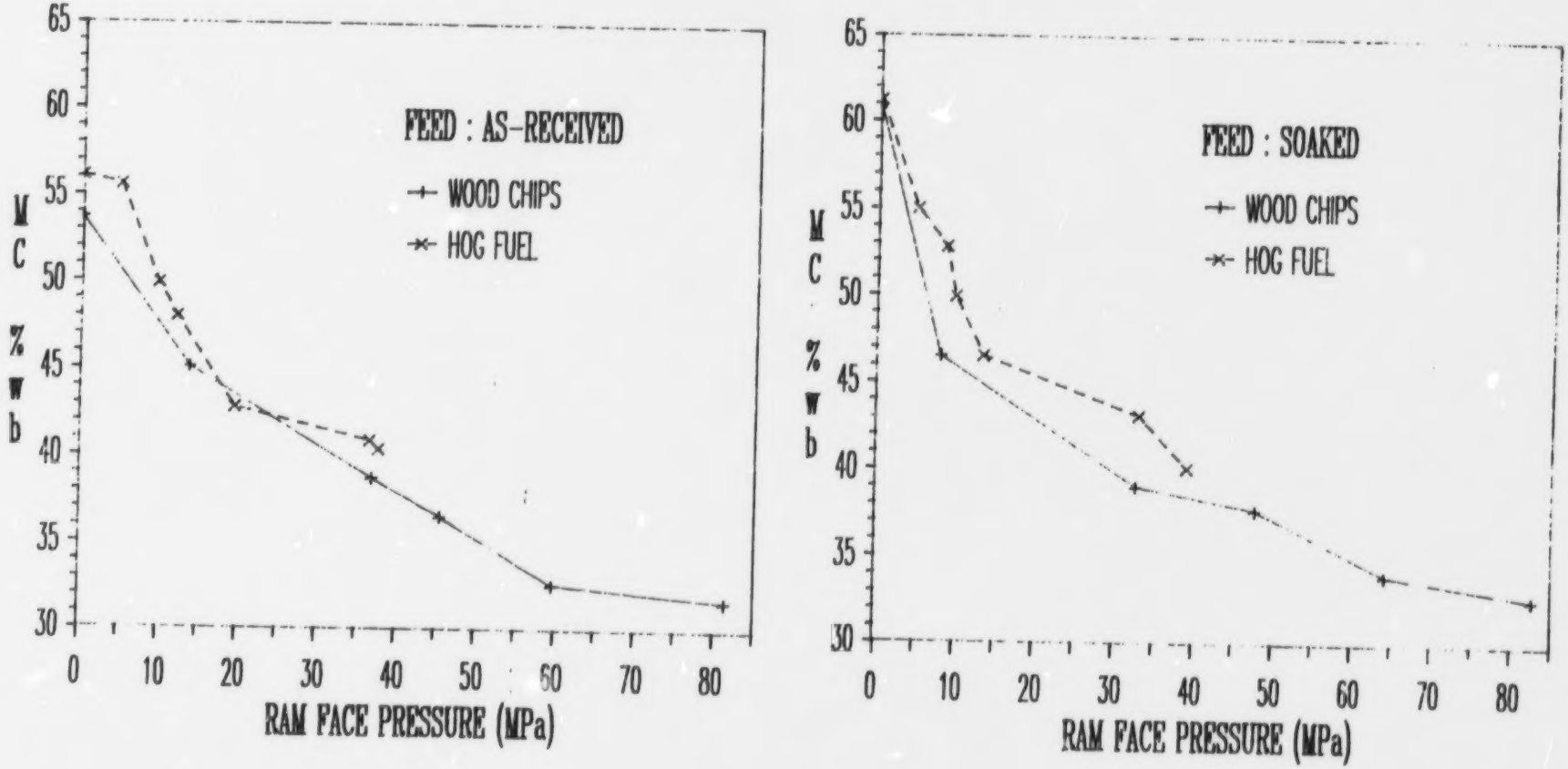


FIGURE VI-19 COMPARISON OF HEMLOCK WOOD CHIPS AND HOG FUEL MOISTURE CONTENTS USING THE RAM PRESS

Results for wood chips with the press setup with and without a perforated barrel are given in Figure VI-20. The product moisture content is clearly reduced by use of the dewatering section upstream of the rollers. There is no significant affect on the product moisture content from use of a shorter feed barrel. Water removal occurs over the full range of pressures tested. The shape of the dewatering curves for as-received and soaked feed used with non-perforated feed barrels are similar, both having about the same rate of moisture content reduction with increasing pressure.

The dewatering curves for hog fuel (Figure VI-21) pressed using various press configurations show that most of the reduction in wet-basis moisture content occurs at pressures between about 10 and 20 MPa. The rate of moisture content reduction with increasing pressure is similar for hog fuel at pressures below and above this range. As found in the tests with chips, use of a dewatering section in the region where the full ram pressure is applied, results in moisture contents lower than what can be achieved with the rollers alone.

2. Effect of Initial Moisture Content

The results for wood chips with and without the perforated barrel show a clear dependence on initial feed moisture content (Figure VI-22). The affect of initial feed moisture content is most pronounced at pressures in the lower half of the range tested. The rate of reduction of moisture content with increasing pressure remains surprisingly constant for the tests with the non-perforated barrel. The rate of reduction of moisture content for tests with the perforated barrel is a maximum for soaked feed between 10 and 30 MPa pressure.

Unlike chips, hog fuel is relatively insensitive to initial feed moisture content (Figure VI-23). The product moisture content for soaked feed material using a non-perforated barrel was found to be higher than that for the as-received feed material, but this difference is much less than found for wood chips.

3. Effect of Type of Feed

Figure VI-24 illustrates the affect on dewatering behavior of the type of feed when using a non-perforated barrel. For feed at as-received and soaked moisture contents, hog fuel requires a higher pressure to achieve the same product moisture content as that of chips. The results from tests using soaked feed indicate that hog fuel requires nearly the same pressure to reach the same moisture content as chips for a product moisture content of near 44%. The two materials when soaked were found to behave similarly at the peak pressures tested.

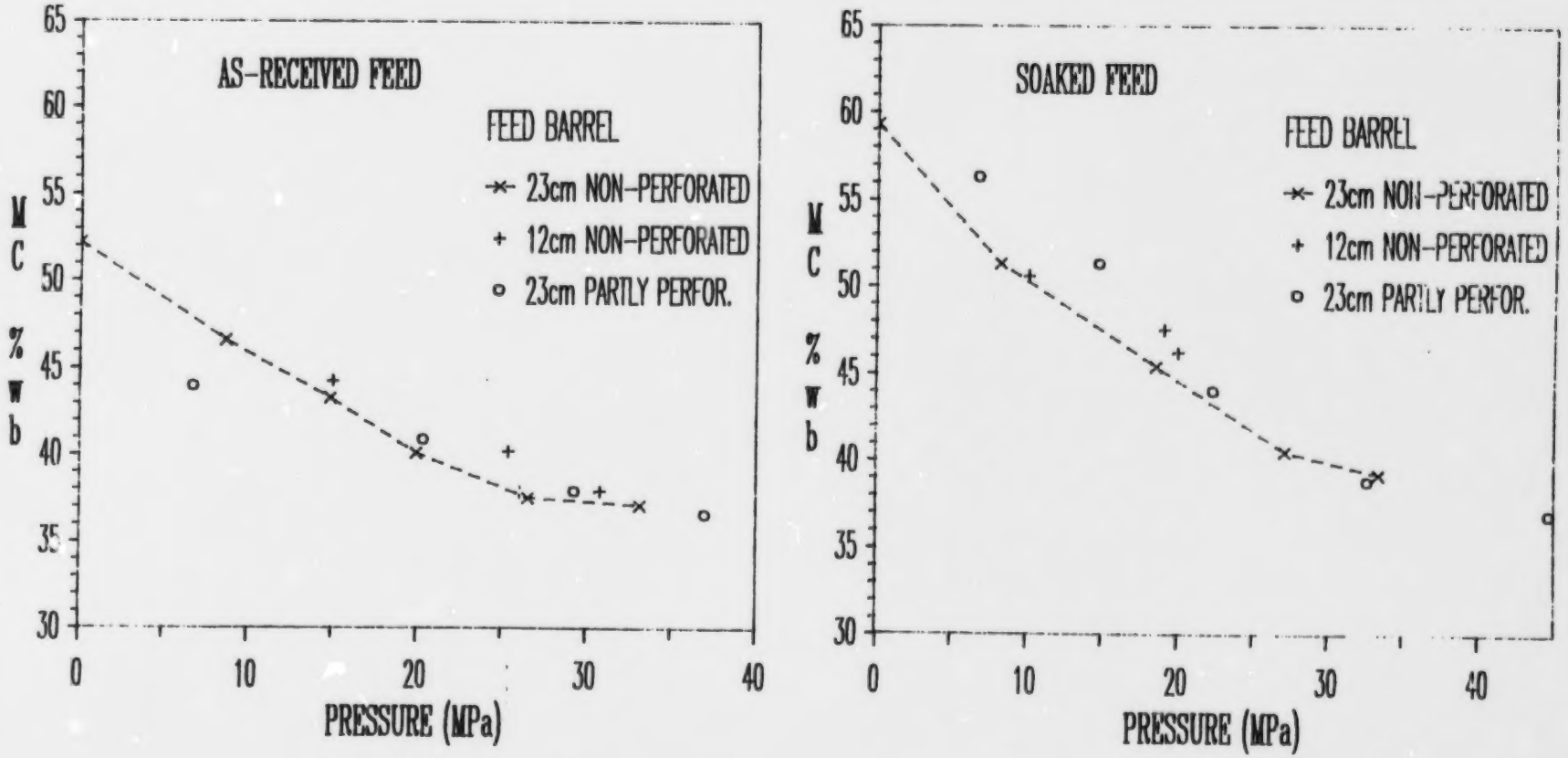


FIGURE VI-20 THE FINAL MOISTURE CONTENT OF HEMLOCK WOOD CHIPS USING THE ROLLER PRESS

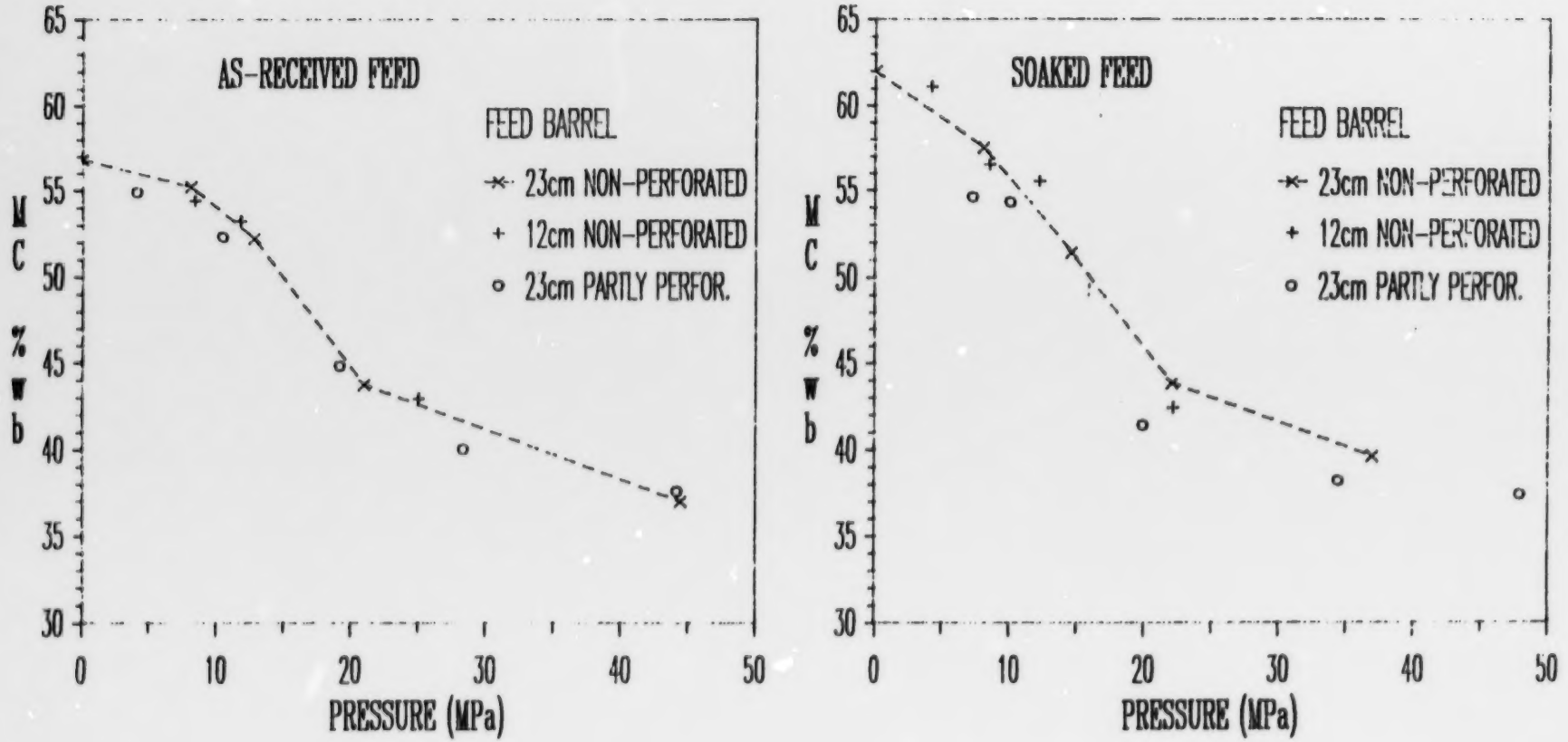


FIGURE VI-21 THE FINAL MOISTURE CONTENT OF HEMLOCK HOG FUEL USING THE ROLLER PRESS

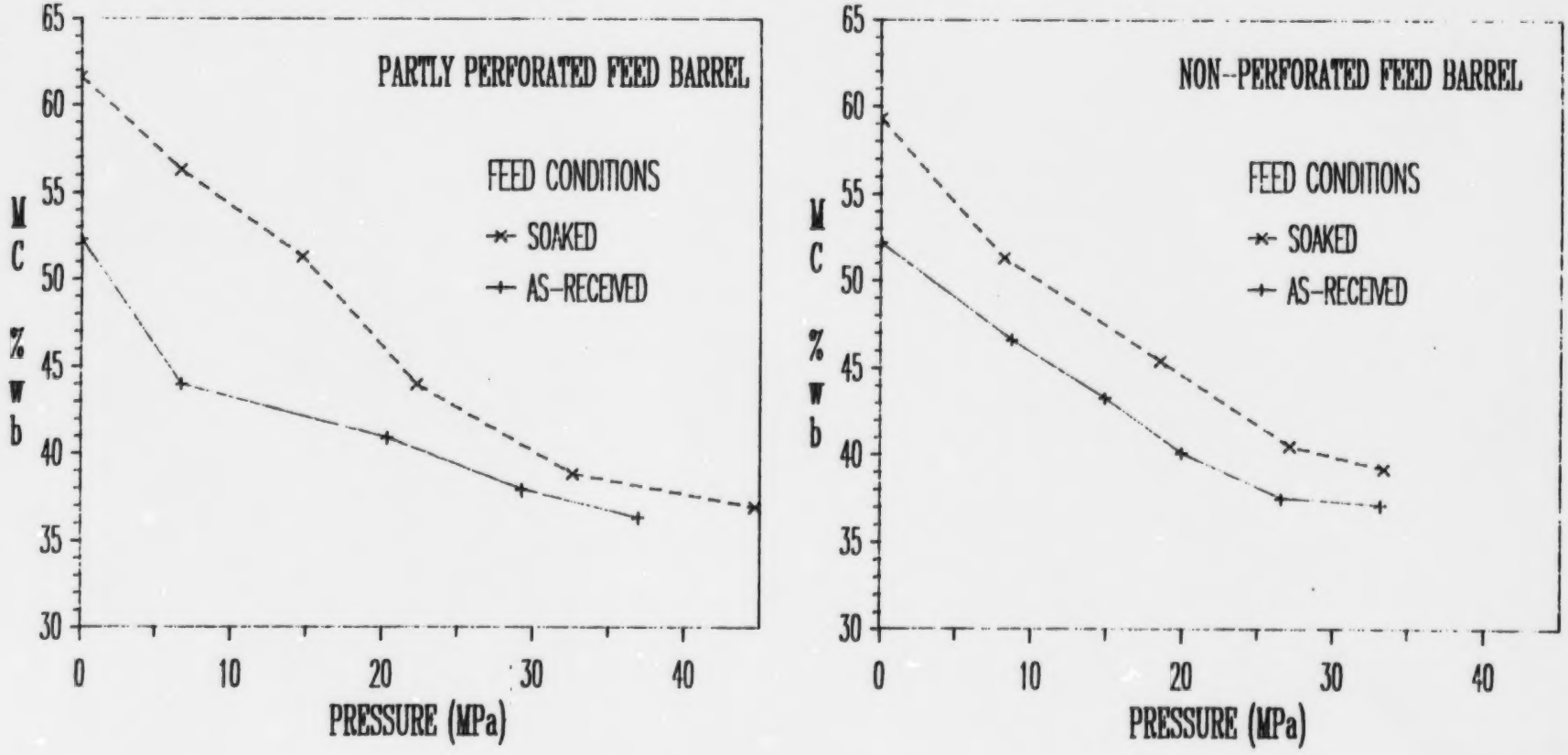


FIGURE VI-22 EFFECT OF INITIAL MOISTURE CONTENT ON THE FINAL MOISTURE CONTENT OF HEMLOCK WOOD CHIPS USING THE ROLLER PRESS

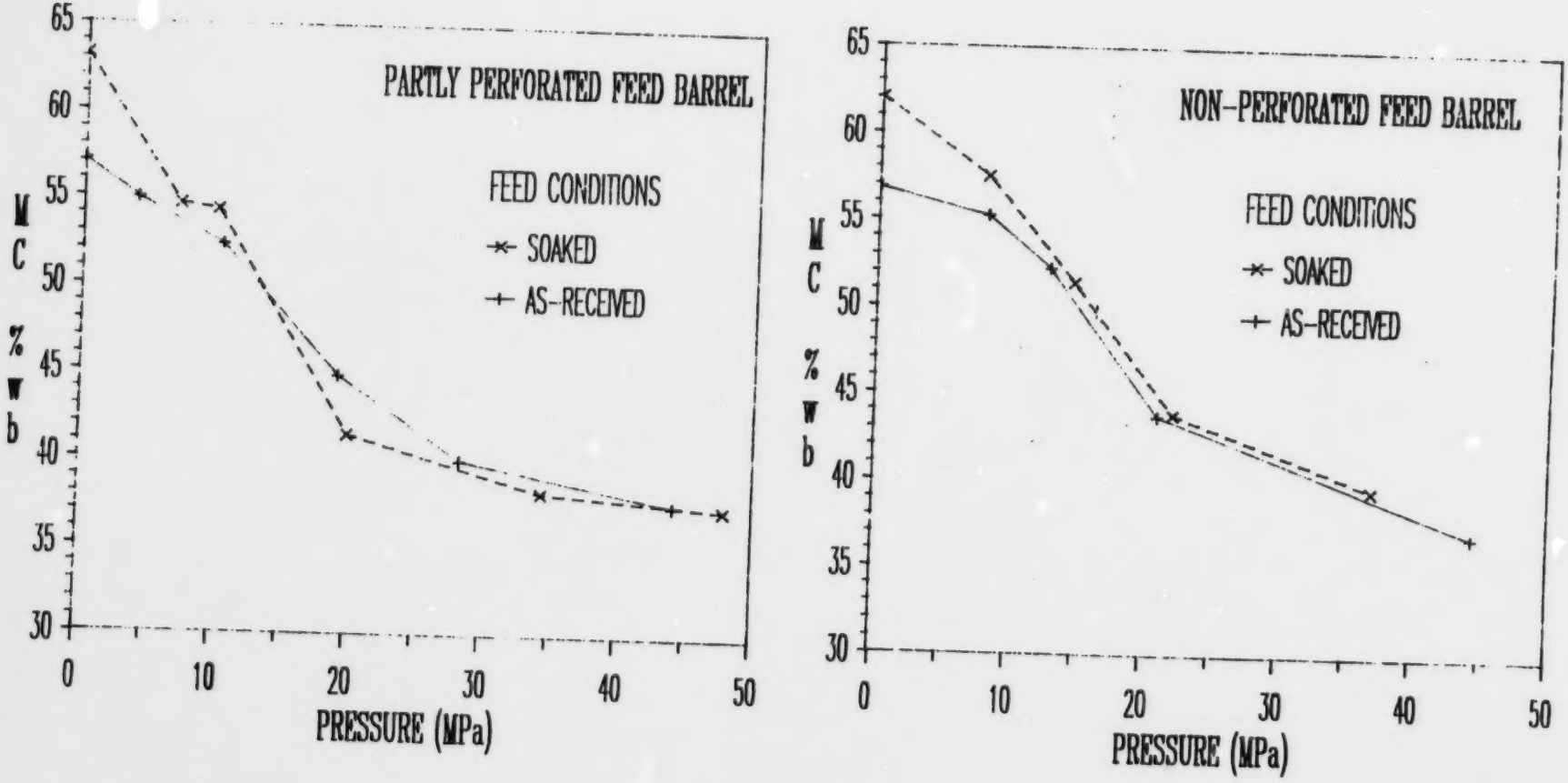


FIGURE VI-23 EFFECT OF INITIAL MOISTURE CONTENT ON THE FINAL MOISTURE CONTENT OF HEMLOCK HOG FUEL USING THE ROLLER PRESS

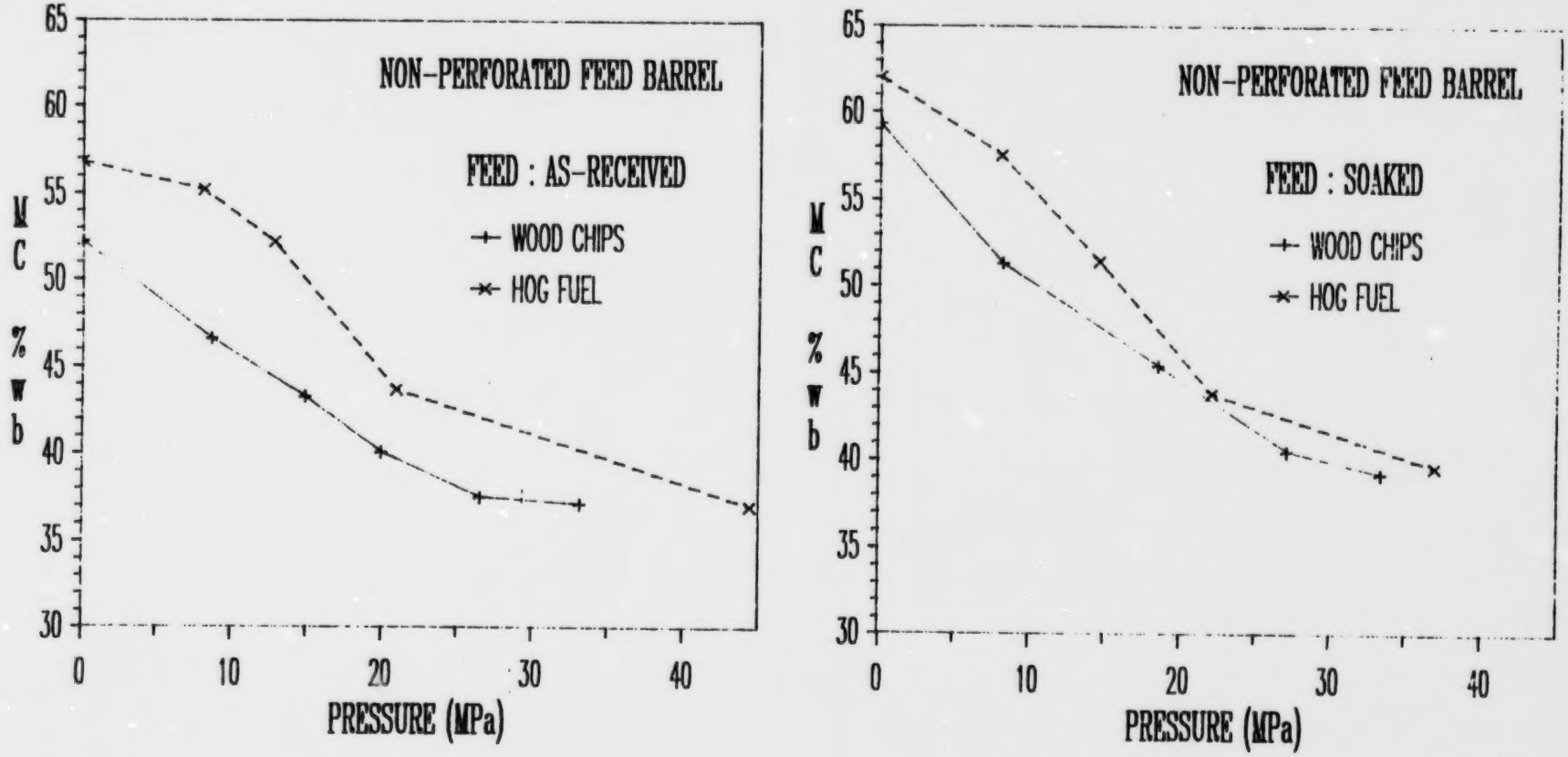


FIGURE VI-24 COMPARISON OF THE PRODUCT MOISTURE CONTENT FOR HEMLOCK WOOD CHIPS AND HOG FUEL USING A ROLLER PRESS WITH NON-PERFORATED BARREL

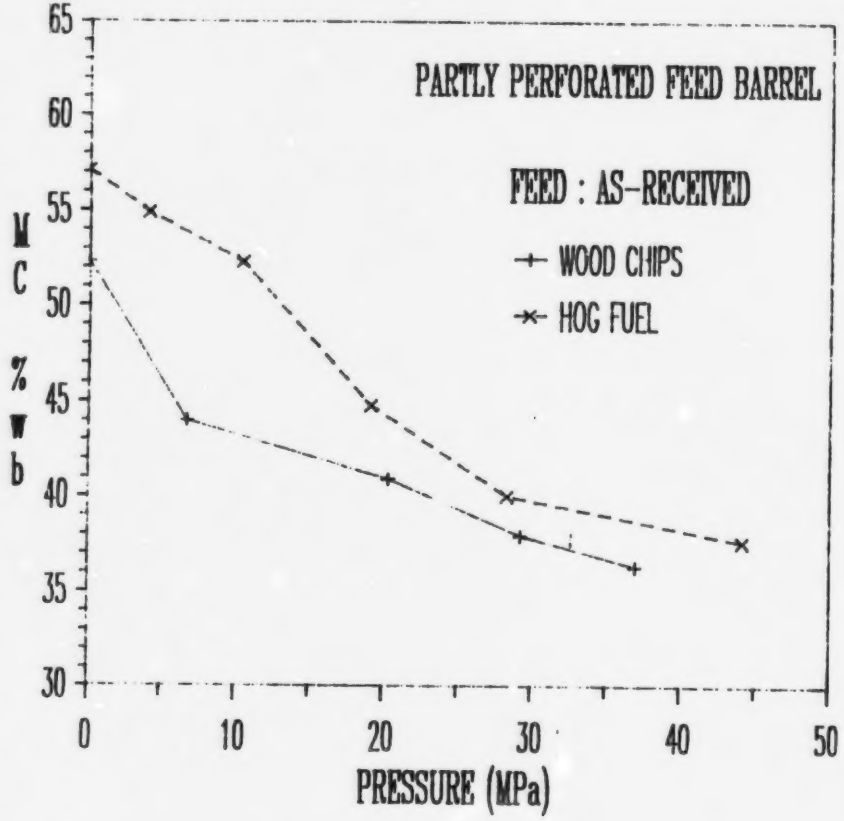
When a partly perforated barrel was used to feed the roller press product moisture content varied with pressure as shown in Figure VI-25. As when the non-perforated barrel was used, the as-received hog fuel required higher pressures than the chips to reach the same moisture content. The tests with soaked feedstock is unusual in that it shows hog fuel to be more readily dewatered. The cause of this is not known.

D. Comparison of Performance of the Presses Tested

One of the objectives of the test program was to identify operating or design improvements for existing dewatering equipment or to develop a conceptual design of a new, improved press. Three different press configurations were tested at a small scale under carefully controlled conditions to produce data for this purpose. The presses were selected and designed to allow study of the behavior of only the parts pressing and allowing removal of water from the feedstock. The units were not intended for study of feeding or product removal mechanisms, and none was undertaken. The feeding and product discharge parts of the test units were intentionally very simplistic in design.

The test units utilize press configurations present in commercial equipment for dewatering wood and bark residues. The data obtained by tests of the three presses cannot be compared directly with performance data for commercial equipment since the test presses operate under fairly idealized conditions and the presses are much smaller in physical size. However, the results from the tests are indicative of what can be achieved by pressing and will show trends that will apply to full-scale equipment. Of particular value is that the three press configurations can be inter-compared leading to conclusions on the most suitable press configurations, the pressures required for each press to achieve a given product moisture content and other matters of importance. The test data also forms a foundation for validation of dewatering theory, as is done in the following chapter for the platen press configuration.

Data from tests with all three presses were compiled to show the moisture content of the product with increasing applied pressure. The calculation of applied pressure was done to arrive at the pressure which existed during the test in the zone where water was removed. This is straightforward for the platen press and the ram press since the pressure applied is that existent at the advancing face. In the case of the roller press, however, there is no direct means of calculating the pressure on the material as it passes through the nip of the rollers. The pressure on the face of the ram feeder is known, but this pressure will not be the same as that in the material present between rollers. The pressure reported for comparison of the roller press with the others tested is the applied load at the ram feeder



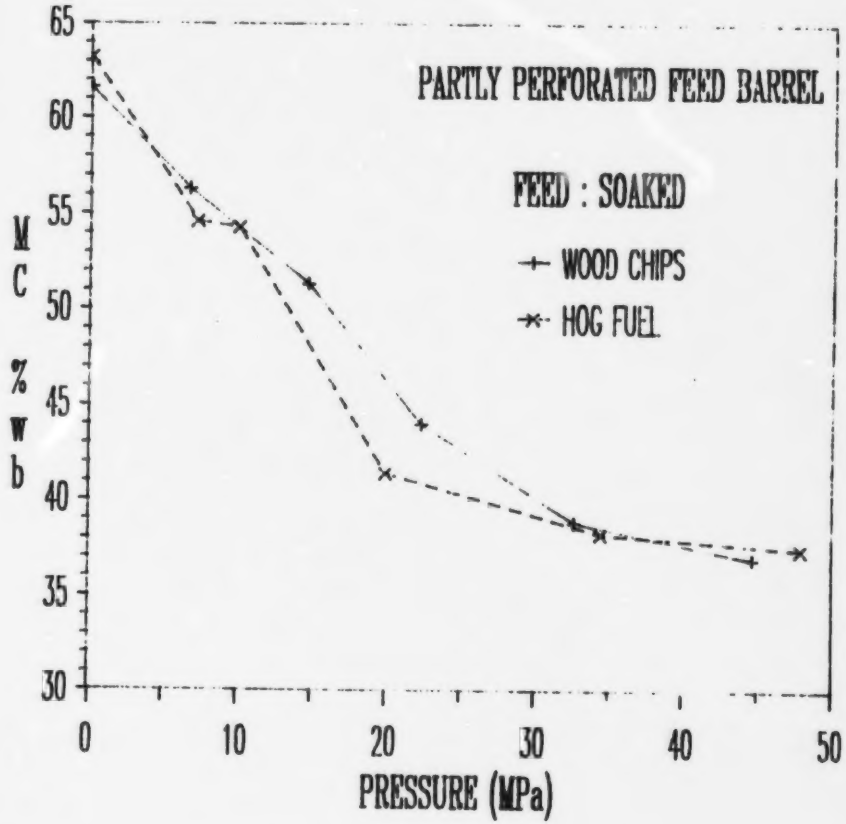


FIGURE VI-25 COMPARISON OF THE PRODUCT MOISTURE CONTENT FOR HEMLOCK WOOD CHIPS AND HOG FUEL USING A ROLLER PRESS WITH PARTLY PERFORATED BARREL

divided by the cross-sectional area of material between the rollers. It is believed that the load transferred to the short section of feed barrel is negligible compared to the total load applied and that the pressure of the material in the nip is the same in all directions (Poissons ratio = 1), behaving much like a liquid.

Figure VI-26 shows the performance of the three presses when using as-received and soaked wood chips. For as-received chips, as in all other cases to be shown later, the platen press yields the lowest product moisture content over the pressure range tested. Because of the slight difference in initial moisture, it is difficult to compare the performance of the roller and ram presses for as-received chips. Since the initial moisture content usually has only a small affect on product moisture content, it appears that the roller press is more effective than the ram press over the same pressure range. Except for one data point, the roller and ram presses have comparable performance when used to dewater soaked chips over the same pressure range. Based on theory and the trends evident in the results, the performance of all three presses is expected to be similar at very high pressures, i.e. over 60 MPa.

The curves for the roller and ram presses are significantly different for hog fuel than for chips (Figure VI-27). As observed for chips, the platen press is the most effective of the presses tested over the same pressure range. In the case of as-received hog fuel, the initial moisture content was unfortunately significantly lower for the platen press than for the other two presses, making comparisons somewhat difficult. However, adjusting the platen press results upward for the case of a higher initial moisture content still would leave them well below those for the other press designs. Somewhat surprisingly, the roller press changes from being less effective than the ram press at pressures less than 20 - 27 MPa to being more effective at higher pressures. This was not observed from tests with chips and must be a result of differences in material properties and particle sizes.

Generally, all of the presses performed more effectively with chips than with hog fuel. This is attributed to the affects of particle size and the fact that no bark was present. The roller press was the least effective at dewatering hog fuel at pressures below 20 - 30 MPa, but became the second best at higher pressures.

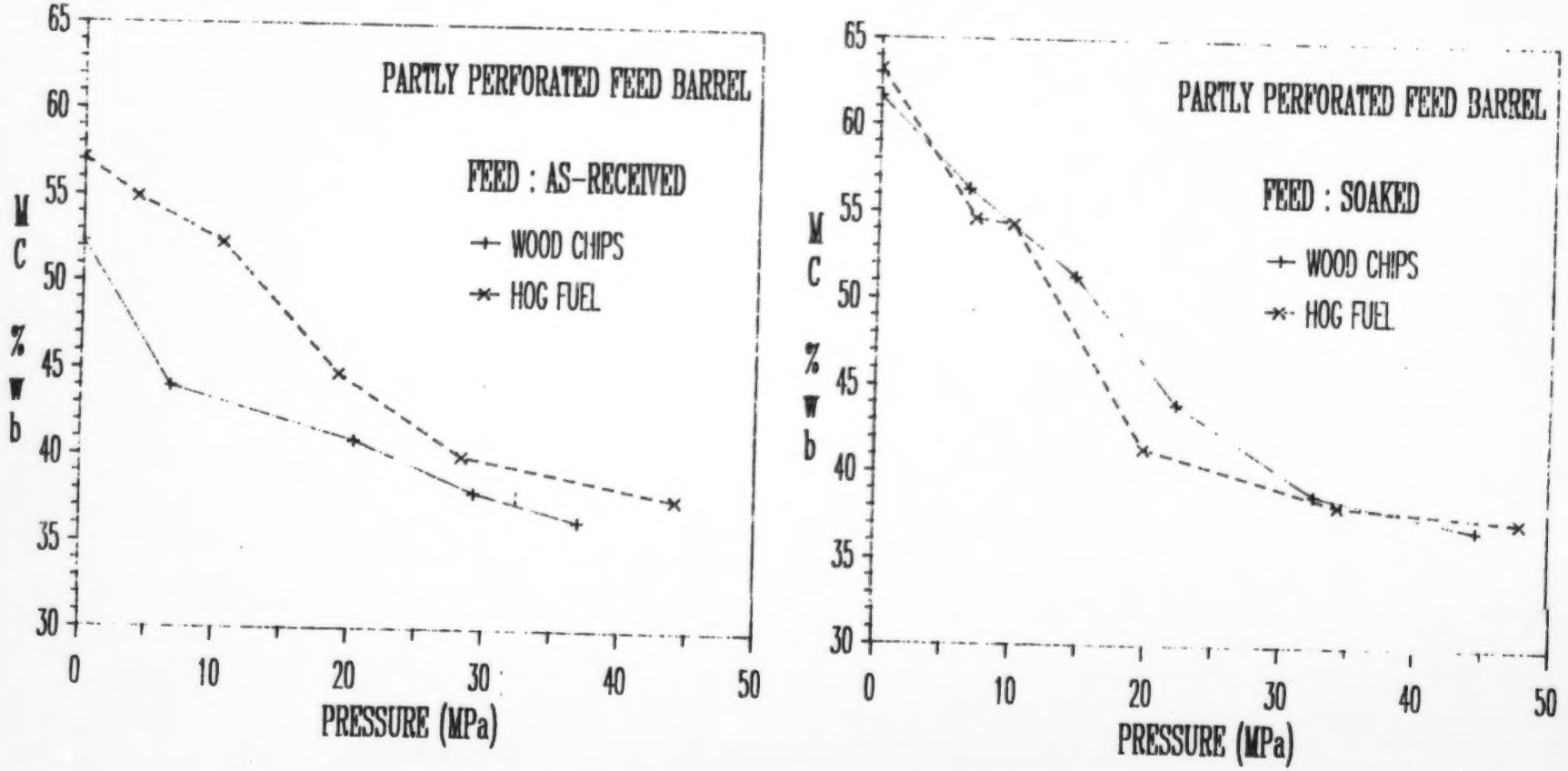


FIGURE VI-25 COMPARISON OF THE PRODUCT MOISTURE CONTENT FOR HEMLOCK WOOD CHIPS AND HOG FUEL USING A ROLLER PRESS WITH PARTLY PERFORATED BARREL

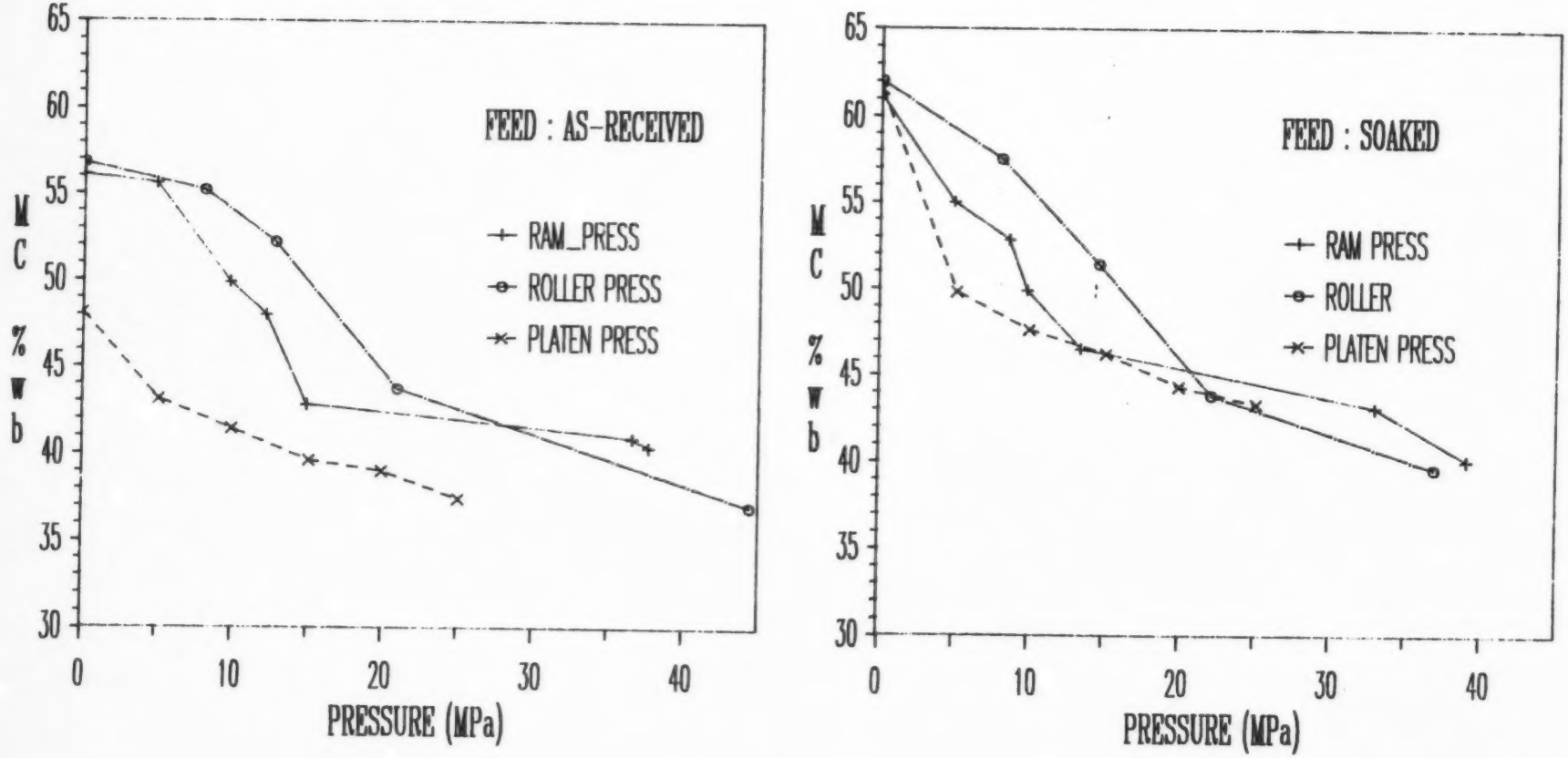


FIGURE VI-27 COMPARISON OF PLATEN PRESS, RAM PRESS AND ROLLER PRESS FOR HEMLOCK HOG FUEL

VII. COMPARISON OF TEST RESULTS WITH THEORY

A. Theory

In Chapter IV a relationship for moisture content was developed as a function of compression (C) and saturation (S):

$$MC = X + S\left(\frac{(1-C)}{SG_i} - k\right) \qquad (1)$$

where MC = moisture content of compressed wood on a dry basis

X = moisture content of wood substance on a dry basis at fibre saturation

C = volumetric compression
= (Initial volume - Final volume)/Initial Volume

SG_i = initial specific gravity of wood as dry wood weight per total wet volume

$$k = \frac{\rho}{\rho_{\text{dry wood}}} + \frac{X\rho}{\rho_{\text{bound water}}}$$

By inspection of early results it was hypothesized that S(1-C) remains approximately constant as compression proceeds. This is equivalent to saying that the theoretical final amount of compression (S approaches 1) is equal to the initial level of saturation (C=0). With this assumption, equation (1) reduces to:

$$MC = MC_i - kS^*\left(\frac{C}{1-C}\right) \qquad (2)$$

where MC_i = initial moisture content on a dry basis

S* = constant
= S(1-C)

A plot of MC versus C/(1-C), therefore, should be a straight line with a slope equal to -kS* and a y-intercept of MC_i. The value of k can be calculated from published data for wood (Haygreen, 1981, Wingate-Hill, 1985; and Edwards, 1977):

$\rho_{\text{dry wood}}$ = 1.5 g/cc

$\rho_{\text{bound water}}$ = 1.1 g/cc

X = 0.3 g/g dry wood

ρ = 1.0 g/cc

With these parameters,

$$k = \frac{1}{1.5} + \frac{0.3 \times 1}{1.1}$$

$$= 0.939$$

B. Analysis of Test Results

To investigate the validity of the relationship for moisture content, data from the platen press tests was analyzed and values were calculated for S, S(1-C) and C/1-C. Values of S(1-C) summarized in Table VII-1 for all tests made with chips and hog fuel show that it is not truly constant over the full pressure range tested. The largest difference in the value of S(1-C) occurs at zero pressure for as-received samples. The value of S(1-C) remains fairly constant over a limited change of pressure.

The relationship for moisture content of compressed material was derived from a simple definition for saturation. Measured values were used to calculate average values of S for all test runs done using the platen press. Values of S, product moisture content and other pertinent data are summarized in Table VII-2 for chips and Table VII-3 for hog fuel. The value of S should be between 0% and 100% in all cases, yet the calculations show this is not the case when using k calculated from typical wood parameters. These results show clearly that S does not remain constant during compression and such an assumption, as made by Haygreen (1985), would not be appropriate. The reasons for calculated values exceeding 100% is not known at this time, but appears to be due to an erroneous value of the fibre saturation moisture content. Additional experimental investigation is needed to more vigorously study the variation of saturation with compression and to determine possibly more appropriate values of wood properties to use in the calculation of k.

The theoretical analysis suggests that a plot of moisture content (dry basis) versus the compression variable C/1-C should be a straight line if S* is constant. As seen in Table VII-1 previously, S* is not constant over the full pressure range so some non-linearity in such a plot may result. In either case, C/(1-C) is a convenient variable for correlating results.

The moisture content of chips after pressing in the platen press is shown in Figure VII-1 as a function of the compression variable C/(1-C). Each data point, except the first one, is the average of four

TABLE VII-1 AVERAGE VALUES OF S(1-C)[a] FOR MATERIALS TESTED

MATERIAL	PRESSURE (MPa)						AVERAGE
	0	5.13	9.97	15.1	19.9	25.07	
Chips, as-received	8.9	11.5	12.3	10.3	12.6	15.2	11.8
Chips, soaked	18.3	15.4	14.9	19.2	18.1	20.5	17.7
Hog fuel, as-received	13.7	18.7	22.1	24.7	23.4	26.0	21.4
Hog fuel, soaked	24.2	23.1	27.1	29.3	27.3	31.6	27.1

S* = S(1-C)

TABLE VII-2 DATA AND RELATIONSHIPS FOR THE PRODUCT MOISTURE CONTENT FOR CHIPS

MATERIAL	PRESSURE (MPa)	C/(1-C)	S (%)	PRODUCT MOISTURE CONTENT (%)	EQUATION[a] COEFFICIENTS A	b	R^2
Chips, as-received	0	0	8.9	91.34	91.946	6.7253	0.9800
	5.13	3.390	50.4	71.85			
	9.97	4.249	64.7	63.57			
	15.10	4.697	58.7	57.15			
	19.94	5.156	77.5	57.32			
	25.07	5.543	99.6	55.60			
Chips, soaked	0	0	18.3	152.78	149.42	16.9307	0.9789
	5.13	3.395	67.9	85.6			
	9.97	4.271	78.7	70.56			
	15.10	5.000	115.3	68.76			
	19.94	5.114	110.7	64.64			
	25.07	5.437	131.7	61.11			

[a] Coefficients for the equation for product moisture content (%, db):

$$MC = A - b\,(C/(1-C))$$

where C = volumetric compression as a fraction

TABLE VII-3 DATA AND RELATIONSHIPS FOR THE PRODUCT MOISTURE CONTENT FOR HOG FUEL

MATERIAL	PRESSURE (MPa)	C/(1-C)	S (%)	PRODUCT MOISTURE CONTENT (%)	EQUATION[a] COEFFICIENTS A	b	R^2
Hog fuel, as-received	0	0	13.7	96.54	97.217	9.1958	0.9900
	5.13	2.675	68.2	74.15			
	9.97	3.280	94.4	68.57			
	15.10	3.526	111.9	65.17			
	19.94	3.681	109.6	61.85			
	25.07	3.913	127.8	60.00			
Hog fuel, soaked	0	0	24.2	153.22	152.667	20.8016	0.9963
	5.13	2.549	82.0	98.24			
	9.97	3.007	108.4	88.64			
	15.10	3.393	128.9	84.75			
	19.94	3.590	125.5	76.38			
	25.07	3.731	149.3	76.34			

[a] Coefficients for the equation or product moisture content (%, db):

$$MC = A - b\,(C(C1-C))$$

where C = volumetric compression as a fraction

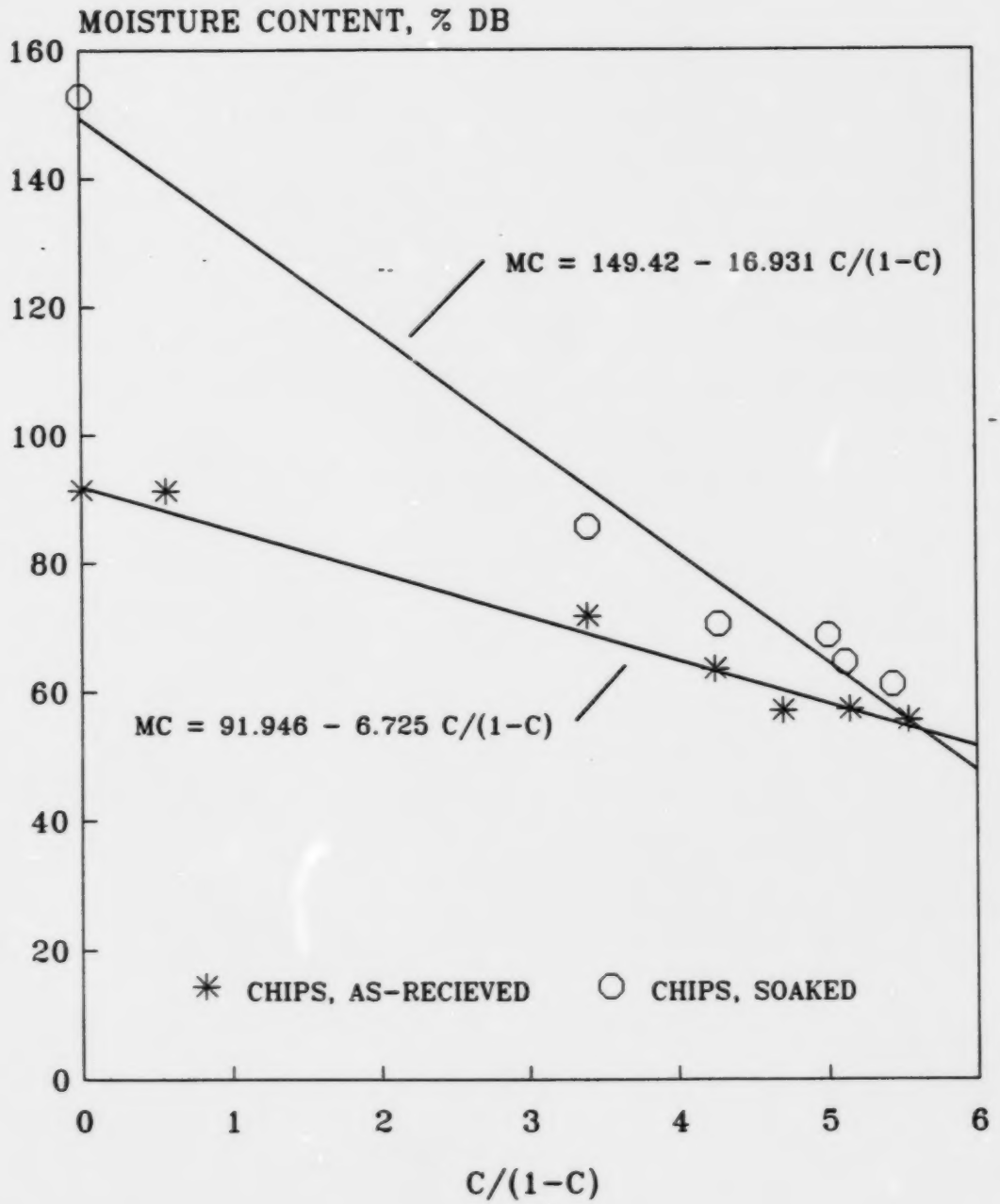


FIGURE VII-1 RELATIONSHIP BETWEEN THE FINAL MOISTURE CONTENT OF HEMLOCK WOOD CHIPS AND C/(1-C)

test runs done at the low loading rate and with a residence time at peak pressure of one to two minutes. The initial moisture content (C = 0) is the average of all twenty runs (5 pressures with four tests each). It is evident from the plot that, in spite of the limitations of the theoretical approach, moisture content decreases fairly linearly with increasing C/(1-C). Tests were not done at pressures below 5.13 MPa, causing a large gap in the early part of the plot. An exception to this is shown for the as-received chips at a value of C/1-C of 0.563. This point was the pressure at which the first observance of water removal was made. For the as-received and soaked chips, water is not removed until some minimum level of compression is reached and the moisture content, therefore, remains constant. Consequently, the dewatering curves should both start at this minimum value of C rather than at the y-axis. Ignoring this initial plateau in moisture content introduces relatively little error, except at low compression levels, which are not of interest because product moisture content remains high. The correlation coefficient (R^2) for the chip test results were 0.980 and 0.9789 for as-received and soaked feed materials, respectively.

Inspection of the correlation for chip dewatering (Figure VII-1) leads to the following conclusions:

- moisture content (dry basis) can be correlated with compression expressed as C/1-C;
- the rate of water removal with compression is higher with samples having a higher initial water content;
- the same product moisture content is reached irrespective of initial water content at some value of compression. This occurs at C/1-C of 5.63 or a compression (C) of 84.9%. The moisture content at this point is 54.08% db or 35.1% wb;
- above a value of C/1-C of 5.63 all feed materials, irrespective of initial moisture content, are expected to have the same moisture content. The slope of the dewatering curve is not known above this compression level. It is possible that the moisture content cannot practically be reduced below 35.1% by pressing only.

Data obtained from tests with as-received and soaked hog fuel are presented as a function of C/1-C in Figure VII-2. As was observed for chips, the product moisture decreases fairly linearly with increasing C/1-C. The decline of moisture content with increasing compression is more rapid with high initial moisture content feed. The data points are averages of at least four runs at the low loading rate and with residence times of 1 to 2 minutes. The equations fit to the data points have correlation coefficients of 0.990 and 0.9963 for as-received and soaked feed materials, respectively.

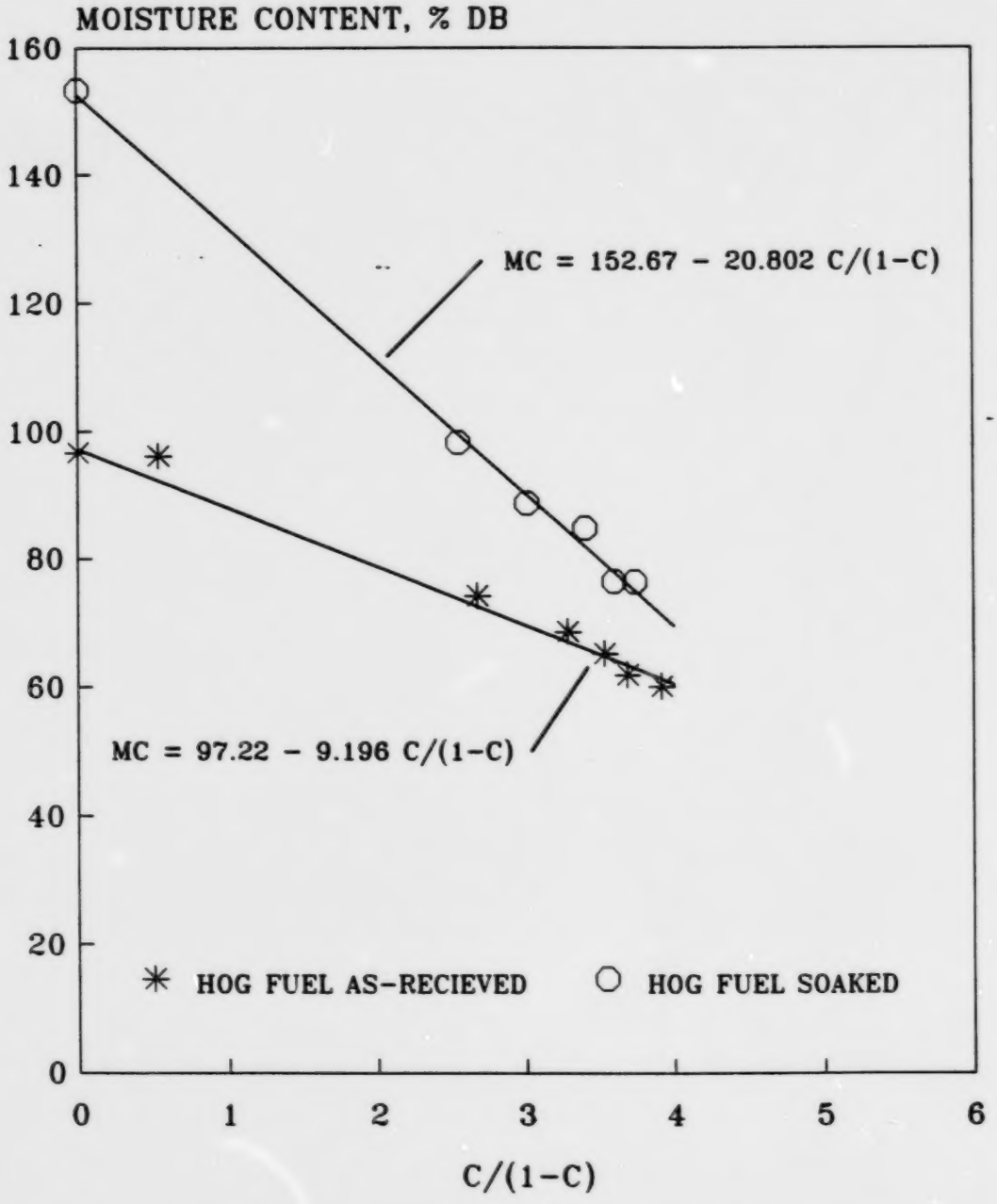


FIGURE VII-2 RELATIONSHIP BETWEEN THE FINAL MOISTURE CONTENT OF HEMLOCK HOG FUEL AND C/(1-C)

The test results suggest that the same product moisture would be achieved for the feed materials tested after compression to a level of 82.7% (C/1-C = 4.78). The moisture content at this compression would be 53.26% db, or 34.75% wb. It is significant and to be expected that this moisture content is essentially identical to that predicted by correlation of the chip dewatering tests.

Comparison of results for hog fuel to those shown for chips indicates:

- the slope of the dewatering line is greater for hog fuel than for chips, and would probably be different again for other types of residues;

- the amount of compression needed to reach a desired product moisture content is less for hog fuel than it is for chips assuming both start at the same initial moisture content;

- the minimum moisture content which could be reached by pressing appears to be near 35% wb, or 54% db.

The correlations developed for moisture content can be used with correlations for compression (C) as a function of pressure. For example Table VI-1 gives the relationship for compression of soaked hog fuel as:

$$C = \frac{65.20}{100} p^{0.0605}$$

Assuming a pressure of 19.94 MPa is applied to the material, C can be calculated to be 0.7814. Substitution of this value into the equation in Figure VII-2 for soaked hog fuel gives the moisture content as:

$$MC = 152.67 - 20.802 \times 0.7814/(1-0.7814)$$

$$= 78.31\%, \text{ db}$$

$$= 43.92\%, \text{ wb}$$

The average experimental value for the above conditions was 76.38%, db, indicating a difference exists of only 1.93%, db or 0.62%, wb.

The correlations developed for compression and moisture content are a valuable tool for studying the affect of material properties, particle size and pressure on dewatering of wood and bark. Additional laboratory testing of other materials (i.e. sawdust, whole bark, etc.), different initial moisture contents, and different pressing conditions are needed to expand and improve the correlations developed in this study.

One area for future work is to extend the results to more complex geometries such as ram presses and roll presses. Results from tests with the ram and roller presses tested in this study could not be analyzed using the developed dewatering theory because of the difficulty of determining the amount the material was compressed (C). This can be done readily with a platen press, but is very difficult for the other presses. Additional work would be needed to pursue correlation of data obtained from tests with the ram and roller presses. However, the method developed for correlating the data is general in nature and, therefore, should apply to any press configuration. The specifics of the press design, particularly the way in which water is removed and pressure is applied, will influence pressing efficiency and water removal, so any correlation will be limited to some degree to the design in question.

VIII. APPLICATION OF EXPERIMENTAL RESULTS TO COMMERCIAL EQUIPMENT

A. Existing Dewatering Presses

Commercial equipment now in use for dewatering wood residues operates over a wide range of pressures. At the low end, the Hooper press operates at up to 2.1 MPa, while at the high end, several manufacturers operate at effective pressures of 17 MPa or larger. Inspection of the graphs showing moisture content as a function of pressure indicates that operation with 20 MPa pressure produces a moisture content of 44 - 46% from very wet feed, similar to what is achieved under optimum conditions by commercial equipment. The experimental results show that product moisture contents of 45 - 55% typically produced by commercial dewatering equipment are consistent with the peak pressures applied. Operation with product moisture contents lower than the typical range could only be achieved consistently by operating at higher pressures than currently used. Benefits could also be derived by optimizing the dewatering press for the material being pressed and by minimizing reabsorption of expressed water. Sufficient time must be allowed for the water pressed from individual particles to drain from the pressed mat.

Laboratory tests demonstrated that the moisture content of hog fuel can be reduced to about 38%, wb by pressing. The lowest observed moisture content for wood chips was 32%, wb. The pressure required to achieve 38% moisture content for hog fuel was 25 MPa when a platen press was used. Much higher applied pressures are needed to achieve this level with the other design tested because of the less effective means of applying pressure to the material itself. The test results show that moisture contents can be achieved under the right conditions that are lower than those found in industrial use of existing presses. The laboratory tests are done under near ideal conditions and it is therefore doubtful that the measured moisture content levels could be achieved routinely with a commercial scale equipment. However, based on the laboratory tests one could reasonably expect product moisture contents of 40 - 45%. This is significantly lower than what is now common for hog fuel and bark.

Design improvements cannot be specified for each commercial press now available because of their many differences and the lack of in-use performance data under known conditions. General design improvements are itemized below that show promise for improving the performance of any press. Based on the results and observations from the test program, the following areas should be addressed to optimize or improve the design of commercial presses:

(a) The press section should be set up to provide a set amount of mat compression, with the amount being determined by experiment or the dewatering theory developed in this study.

(b) The control system should regulate volumetric compression not applied pressure. The relationship between compression and pressure can be determined either by experiment or using equations of the form developed in this study.

(c) The presses operating conditions should be changed to suit the material being pressed. Optimum conditions vary with the size distribution and type of material being pressed. The affect of these changes on the performance of the press is significant.

(d) The duration of pressure application should be maximized. Results of tests with platen presses suggests pressing up to 1 minute is needed. The duration of the other parts of the pressing process can be minimized to the extent practical with no affect on discharge moisture content.

(e) The water drainage section should be examined to minimize the time the water remains in contact with the mat, especially when pressure is being released and there is a possibility for reabsorption.

(f) Where possible the press section should approximate a platen press configuration since this arrangement has been found to yield the lowest moisture content for a given level of applied pressure.

(g) The material to be dewatered should be fed to the press section in a uniform thickness to promote uniformity of compression and dewatering.

The survey of users conducted for this study suggested there is greater satisfaction with current presses using rollers in various arrangements than with other presses. Roller presses are well suited to high throughput and avoid structural problems and complexity often associated with reciprocating press designs. However, the laboratory results indicate that roller presses are less effective than platen presses in removing water, at least when two opposing rollers are used. The performance of presses using alternate roller configurations cannot readily be determined from the results from the roller press used in this study, but the performance is expected to be similar. Lower moisture contents can undoubtedly be achieved by using a series of pressing stages so multi-nip presses would be better than a single-nip press, as used in the test unit.

The stick and slip phenomenon observed with the ram press suggests that a similarly designed commercial press would have serious problems if operated at the desired pressures. The main problem would be high stresses arising from the stock loads with each stick-slip event. The Ram press design tested was found to be less effective than a platen

press design at the same pressure. This behavior is expected for full-scale equipment.

B. Potential New Dewatering Press Designs

1. Platen Press

Haygreen (1985) developed and tested a large pilot dewatering press which utilized a platen press configuration. The pilot tests were used as a basis for specification of the major design parameters for a prototype unit capable of dewatering a 0.51 m^3 charge of residues; whole tree chips were used as a basis in this case. The 0.51 m square hydraulically actuated ram specified in this design would operate at a maximum pressure of 17.2 MPa and with three minutes per press cycle. Side plates made of Johnson screens were recommended for the lower part of the press chamber. Water would drain down the side of the chamber and out the bottom. The press would be oriented vertically, with feed entering the chamber from the top and dewatered material being pushed cyclically out the bottom after opening of a sliding door.

The conceptual design developed by Haygreen could process 1.8 dry t/h of wood chips, reducing its moisture content to an expected level of 43% from an initial level of 60%. Lower moisture content could be achieved when starting with dryer feed material.

Development of a prototype platen press for commercial dewatering of wood residues was not undertaken upon completion of pilot tests. The scale of the proposed prototype was considered to be a reasonable step from the pilot unit. Testing of a unit of such a size was recommended before attempting development of a larger press.

The physical size of a platen press design, such as of the design suggested by Haygreen, and the massive hydraulic cylinder and circuit needed to drive the ram make this design unattractive for commercial use. There are no known design improvements or results which would suggest a platen press is commercially practical for dewatering wood residues. Development of such a press design is not recommended.

2. Other Designs

Tests conducted with the three laboratory scale presses provided data which can be used to compare the performance of platen press, ram press and roller press configurations. The theory developed for dewatering and applied to a platen press

provides a basis for understanding the affects of material and press variables on the dewatering process and can be used to assist design of dewatering presses. Experimental data and dewatering theory have been used to formulate design specifications and develop a new press design.

The following general and somewhat idealized design specifications for a wood residue dewatering press were developed from the experimental and theoretical findings of this study, in conjunction with information on the needs of industry:

- the press should achieve a high level of compression; for example, a compression of 80% or more is needed to reduce hog fuel moisture content to 41%, wb from 60%, wb;

- the press should be able to develop a pressure on the material in the dewatering zone of 25 - 30 MPa to reduce moisture content to 40 - 45%, wb;

- the thickness of the compressed mat should be larger than the largest piece of foreign material (metal, rocks, etc.) that may pass through the press (say 50 mm);

- there should be minimal sliding contact between the pressed material and the pressing surface, especially in the zone of highest pressure;

- the means of applying pressure should approximate a platen press to achieve a high pressing effectiveness;

- the residence time of material in the dewatering zone should be of the order of one minute or more;

- the throughput of the press should be 7 - 10 dry t/h;

- the amount of compression should be able to be regulated under automatic control;

- the design should be such that fatigue failure of parts is avoided;

- the design should minimize maintenance costs by the use of replaceable wear surfaces, by allowing easy replacement of damaged parts and by the use of design features which avoid or minimize plugging of the dewatering zone perforations.

All of the commercial wood residue presses now available can significantly reduce feed moisture content. They each address the above design specifications to different extents and in different ways. None of the available designs achieve the recommended

pressures and, for this reason, the product moisture contents are always greater than 45%, wb and usually in the range of 50 - 55%, wb. The above design specifications are for an improved design which would be capable of reducing the feed moisture content to 40 - 45%, wb for any initial feed moisture content.

Guidelines for improving the performance of exisiting presses are given in the previous section. The above design specifications could also be used to assist manufacturers in modifying their designs and lowering product moisture contents to 45%, wb or less. Detailed study of specific designs and field trials of modifications are needed to proceed along this course. The potential for improvement of existing designs appears high.

A new press design is proposed for dewatering wood residues. This design was developed with consideration of the design specifications listed above, and the advantages and disadvantages of current commercial equipment. Figure VIII-1 illustrates the main elements of the design. The press utilizes two dewatering zones, the first being produced by the feed screw, the second being produced by the roller operating inside a perforated drum. The screw precompacts the material, reducing the amount of compaction which has to be developed by the roller, and removes some water through a dewatering barrel. The diameters of roller and drum are similar, thus providing a relatively large dewatering zone and maximizing the time pressure is applied. Material is taken out from between the drum and roller where the gap width is a maximum and all pressure has been released. One or more passes of material through the dewatering zone between the roller and the drum may be used. If more than one pass is used then a guide vane should direct the material flow in a spiral along the drum and a means of controlling mat height where material enters the second and each subsequent dewatering zone should be provided. Preferably only one dewatering zone in the roller press should be used. The minimum gap between the roller and drum should be set at a value which avoids damage from foreign material. The undriven drum rides on bogies providing sufficient support to prevent fatigue failure. The roller is controlled hydraulically to maintain the desired level of compression. In this regard, uniformity of feeding and initial mat thickness is critical to achieving good press performance. The roller is driven at a rate which yields the desired throughput and duration of pressing. Multiple pressing stages will be needed if the desired pressing time cannot be achieved when operating at the desired throughput.

The proposed design differs from the Saalasti-Oy press in that the diameters of the roller and drum are more similar in size, producing a larger pressing zone and increasing the time materials are exposed to high pressure. Unlike all presses currently used, the proposed design uses two dewatering stages.

The first stage is in the screw feeder which removes water at low pressure and regulates the thickness of the mat entering the roll press. Control of the initial mat thickness is important since a specific amount of volumetric compression must be achieved.

The proposed dewatering press should be developed and tested at a laboratory scale. This will allow testing of its performance with various materials under a range of operating conditions. Development of a prototype would logically proceed if the small scale tests were successful.

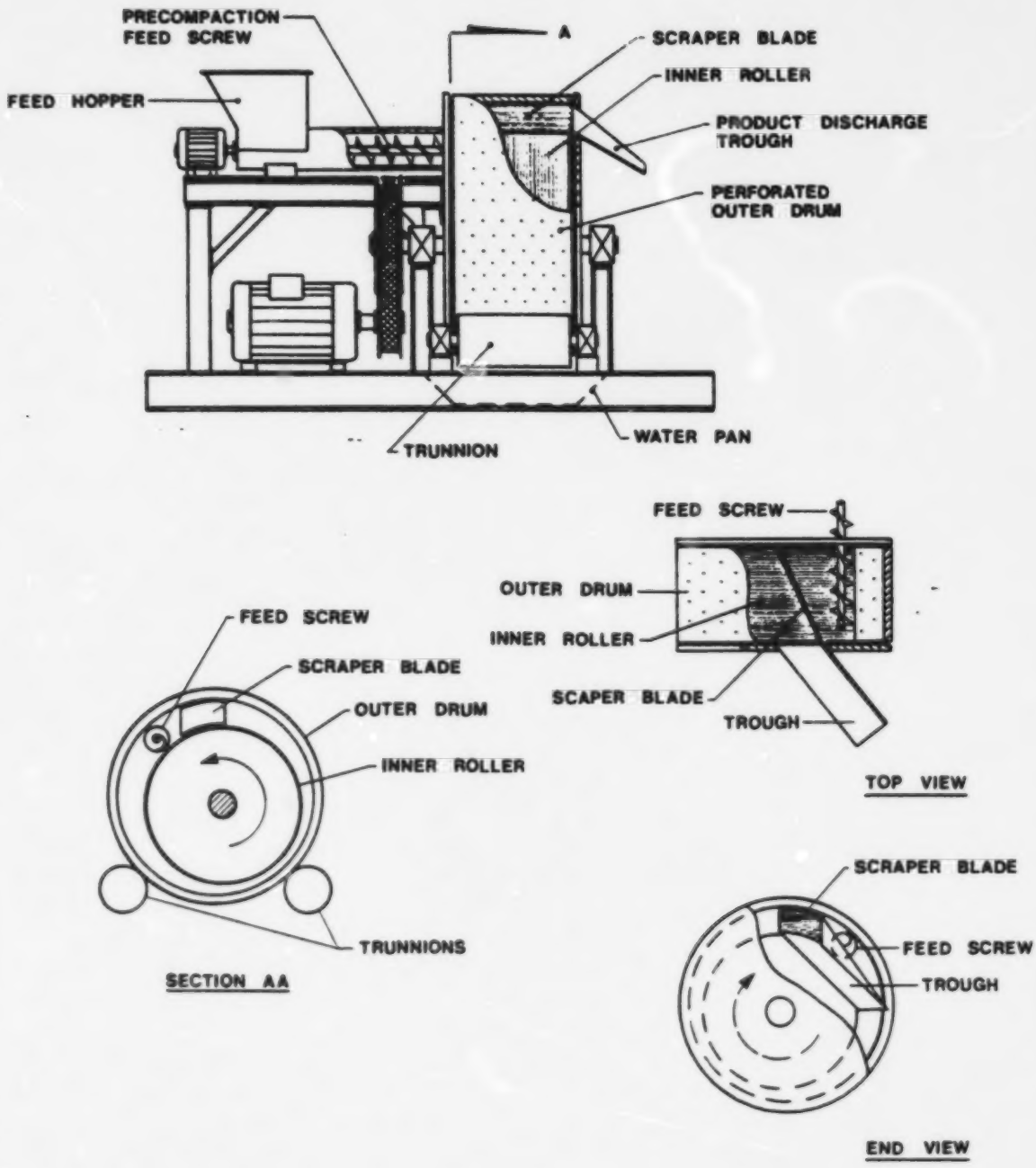


FIGURE VIII-1 CONCEPTUAL DESIGN OF A NEW DEWATERING PRESS

IX. RECOMMENDATIONS

A. Further Experimental and Theoretical Work

1. Additional testing with the platen press test unit should be done, particularly in the range of compression not considered in this study to improve the correlation and determine whether or not it can be applied over the full range.

2. Additional testing with the platen press using feed materials of different moisture contents to develop a correlation which incorporates the effect of initial moisture content.

3. Rationalization of the correlation coefficients and the physical properties of the material should be done using all available test data. This should assist in determining the influence on dewatering of specific gravity, wood substance moisture content etc.

4. If the theoretical approach is successful at explaining the dewatering process for a platen press, it should be generalized so it can be used to analyze other press configurations. Suitable experimental data should be measured for this purpose. Analysis of any designs now used in commercial equipment would be of value.

5. Data from full-scale units should be obtained in sufficient completeness that it can be correlated using the developed theoretical approach. These results should then be compared to laboratory findings to identify similarities and differences. If the correlations developed for the laboratory can be applied equally well, or after simple adjustments, to the full-scale case, the task of optimizing dewatering presses can be done more economically and readily through laboratory studies.

B. Commercial Equipment

1. In Section A of Chapter VIII is a list of changes and means of making improvements to commercial dewatering presses. Specific recommendations to optimize commercial presses can only be given for each specific design and only when complete field data is available.

2. Detailed performance data for one or more of the more popular commercial presses should be compiled either by obtaining information from mill personnel or by direct measurement. The preferred approach is to conduct a field test of case studies to ensure the data is complete and the test was done under suitably controlled conditions.

3. Provisional on the success of generalization of dewatering theory to a roll press configuration, laboratory testing should proceed on the proposed press design. Scaling relationships should be developed before construction of a test unit to ensure one can be sized to yield results indicative of a full-scale model.

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